AFRL-RH-WP-TR-2008-0007

Better Decision Making Through Representation and Reduction of Uncertainty in C³I Information System

Michael S. Brickner
Dganit Sheffer
Yishai Alef
Ido Brickner

PAMAM – Human Factors Engineering Ltd.
35 Hayarkon Street
Bnei Brak 51204 Israel

Amit Sirkis

Center of Operational Research
Israel Defense Forces
Tel Aviv Israel

November 2007

Interim Report for the Period October 2006 to September 2007

Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7022

NOTICE

THIS REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

AFRL-RH-WP-TR-2008-0007

//SIGNED//
GILBERT G. KUPERMAN
Work Unit Manager
Cognitive Systems Branch

//SIGNED//
DANIEL G. GODDARD
Chief, Warfighter Interface Division
Human Effectiveness Directorate
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
November 2007

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
October 2006 – September 2007

4.TITLE AND SUBTITLE
Better Decision Making Through Representation and Reduction of Uncertainty in C^3I Information System

5a. CONTRACT NUMBER
FA8650-04-D-6405

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
[1]Michael S. Brickner, [1]Dganit Sheffer, [1]Yishai Alef, [1]Ido Brickner, [2]Amit Sirkis

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
7184X06C

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
[1]PAMAM - Human Factors Engineering Ltd.
35 Hayarkon Street
Bnei Brak 51204 Israel

[2]Center of Operational Research
Israel Defense Forces
Tel Aviv Israel

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
Human Effectiveness Directorate
Warfighter Interface Division
Cognitive Systems Branch
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/RHCS

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RH-WP-TR-2008-0007

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
88th ABW/PA cleared on 13 February 2008, WPAFB-08-0359.

14. ABSTRACT
This research program deals with ways by which the representation of battlefield information in general and information about uncertainty in particular, may enhance Decision Making, Situation Awareness (SW) and Sensemaking in battlespace environments. Previous stages of research were based on observations by the research team in a company-level simulation experiment and a brigade-level field experiment. The present stage included observation and analysis of controlled experimental research that took place in the Israel Defense Forces Battlefield Laboratory (BatLab). A Battle Management System (BMS) was conceptually designed by PAMAM and developed for the experiment by the BatLab.

15. SUBJECT TERMS
Decision Making, Situation Awareness, Sensemaking, Battle Management System (BMS)

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Gilbert G. Kuperman
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	80	**19b. TELEPHONE NUMBER** *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

THIS PAGE LEFT INTENTIONALLY BLANK

Table of Contents

List of Figures

List of Tables

Preface

This report was prepared by PAMAM Human Factors Engineering, Ltd., Bnei Brak, Israel, under a grant from the European Office of Aerospace Research (EOARD), London England. The research reported was conducted with the support of the Cognitive Systems Branch, Warfighter Interface Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/RHCS), Wright-Patterson Air Force Base, Ohio. Lt. Col. Robert Kang (EOARD) was the Contract Manager and Mr. Gilbert G. Kuperman was the AFRL Work Unit Manager.

The experiment was conducted in the Battle Laboratory of the Center of Operational Research, Israel Defense Forces under the command of Lt. Col Amit Sirkis. We wish to thank the staff to the laboratory for their efforts and support.

The authors also wish to acknowledge the interest and support of Lt. Col. Michal Hovev, Head, Human Factors Basic and Applied Research Unit, Defense Directorate of Research and Development (MAFAT), Israel Ministry of Defense (IMOD), Tel Aviv, Israel. The authors also wish to express their gratitude to the personnel of the Israel Defense Force (IDF) who served as subject matter experts during the conduct of this research.

THIS PAGE LEFT INTENTIONALLY BLANK

Overview

The current research program deals with ways by which the representation of battlefield information in general and information about uncertainty in particular, may enhance Decision Making, Situation Awareness (SA) and Sensemaking in battlespace environments (Brickner and Lipshitz, 2004). Previous stages of research were based on observations by the research team in a company-level simulation experiment and a brigade-level field experiment (Brickner and Sadot-Parag, 2005a,b – See Appendix 3). The present stage included observation and analysis of controlled experimental research that took place in the Israel Defense Forces Battlefield Laboratory (BatLab – Appendix 4). A Battle Management System (BMS) was conceptually designed by PAMAM and developed for the experiment by the BatLab. Because of the high complexity inherent in operational situations and scenarios it was decided to perform this experiment within a relatively restricted battlefield and with a low level of command. Additional, more complex, missions may be simulated and run in the future.

The research literature on BMS Human Factors in general and uncertainty representation in BMS in particular, is based primarily on qualitative measures: Task analyses, questionnaires, Subject Matter Expert (SME) interviews, reports of observers, etc. (e.g., Bisantz, Kesevadas, Scott, Lee, Basapur, Bhide, Sharma and Roth 2002). Our goal, however, was to use experimental tools that will provide quantitative performance measures. A novel research methodology was developed by PAMAM in order to cope with the methodological problems associated with running a controlled experiment in a complex command and control environment. This environment (described below) allows the scenario to develop naturally but restrains the development of high levels of variability by "resetting" the situation at predefined decision points. A SME prepared eight highly detailed operational scenarios that were programmed and implemented by the BatLab (see Appendix 1 for an exemplary scenario).

After a series of pretests and adaptations, 16 SMEs from the Israeli Defense Forces (IDF) were randomly assigned to two groups; eight in the experimental uncertainty group and eight in the control group. All subjects performed all of the eight scenarios: two training and six experimental scenarios. The control group performed the scenarios with standard tactical symbols on the BMS whereas for the experimental uncertainty condition special additions to the tactical symbols were developed by PAMAM (Appendix 2). The experiments were run in the BatLab by BatLab staff, under the professional supervision of PAMAM. Each experiment lasted approximately four hours and included the two training and six experimental scenarios.

The representation of uncertainty did not have an overall effect on decision making quality but had a significant effect on seven out of the 30 decision points (five decision points within each of the six experimental scenarios). At each decision point subjects could ask for additional information from one or two sources, for the "price" of expending some time. Additional information had a significant positive effect on decision making performance. Patterns of information request were different in the experimental group than in the control group. Large individual differences were found between SMEs some of whom demonstrated high levels of command and control expertise while others seemed to lack sufficiently deep understanding of the relations between the BMS and reality. There were also large individual differences in rates of additional information requests. Subjects' SA probes, using the Situation Awareness Global Assessment Technique (SAGAT - Endsley, 2000) showed that, most of the time, subjects were capable of maintaining reasonable good control of both the near vicinity of the blue force and the relevant periphery. No clear differences in SA were found between the experimental and the control group.

In spite of the restrictions imposed by the research methodology (i.e., subjects required to make forced choice decisions and acquire additional information only at pre-defined locations), the SMEs expressed overall highly positive opinions of the experiment, the operational environment, scenarios, decision points, additional information and SAGAT probes. Furthermore, some of them expressed their wish to use such a system as a training environment. The representation of uncertainty was evaluated to be a useful idea both in general (enhancing the understanding that the BMS information contains inherent uncertainty) and specifically (representing known sources of uncertainty). It should be noted that these opinions were only partially reflected in the subjects' performance.

Our conclusion is that uncertainty information (when available and reliable) should be available to commanders as an optional layer of information on the BMS.

Another important lesson is that available information was underused, resulting in sub-optimal decisions. It is not completely clear why several subjects refrained from requiring available information. Obviously, however, this kind of behavior was counterproductive and ways of changing it should be devised.

Some individual subjects were excellent decision makers whereas several others did quite poorly. A cognitive task analysis is recommended in order to better the understanding of the basis and the sources of good battlefield decision making and impart it with the less proficient commanders.

Some potential future research issues are Outlined in the "Recommendations and Future research" section.

Introduction

In recent years the technology for acquiring, processing distributing and displaying battlefield information has been constantly developing. Based, in part, on the information revolution in the commercial sector the military strives to replace existing hierarchical information systems with a network approach in which all participants may serve as sources as well as clients of information (Leedom, 2001, 2002, 2004). One important consequence of such approach is a much wider distribution of Command, Control, Communication and Intelligence (C^3I) information devices. Systems that in the past were the sole property of high level command and major platforms (e.g., bombers), are gradually being deployed to low level units and even to single shooters (for example, helicopters, tanks, infantry soldiers - e.g., US Army Land Warrior Program – e.g., ARNEWS, 2006). Theoretically, the high availability of information should lift much of the "fog of war". Nevertheless, the growing complexity of the battlefield may outweigh improved means for obtaining, distributing and displaying information, thereby maintaining high levels of uncertainty (Brickner and Lipshitz, 2004). The modern battlefield may contain great numbers and varieties of objects, many of which may be highly dynamic and many of which may be well concealed. Furthermore, the very nature of war seems to be changing from conflicts between national armies to conflicts between armies and various types of guerilla organizations (e.g. the Israel - Palestinian conflict, US wars in Iraq and Afghanistan). This type of adversary tends to be small, agile, mostly concealed and with very low signatures; they are, therefore, very hard to detect and recognize.

Information and uncertainty in the commanders' "information world"

Commanders plan, command and control missions that take place in the real world. The term "information world" (Brickner and Lipshitz, 2004) describes the combined information that is necessary for the performance of these missions. The "world" can be divided into four dimensions:

- The physical world (geography, topography, atmosphere).

- Friendly forces (commanding levels, commanded forces, own unit, other units, neutral forces).
- Enemy (sites, targets, threats).
- Mission stages (planning, mission performance, debriefing).

Brickner and Lipshitz (2004) suggested defining "uncertainty" as the gap between reality and the actual knowledge (or situation awareness) of the commander. Several sources may contribute to uncertainty. This definition is somewhat similar to the one used by Matthews and Shattuck (2001) who preferred to look at the "positive" side of the same coin and refer to SA rather than to uncertainty. Brickner and Lipshitz (2004) distinguished between "objective uncertainty" that represents the gap between reality and its representation on the BMS (e.g., limited acquisition abilities, inefficient distribution, inadequate BMS systems) and "subjective uncertainty" that may be added due to limitations of the human operator (e.g., deficient expertise, lack of attention). (Figure 1).

The present report is about "objective uncertainty". It is argued that the overall system may have some knowledge regarding objective uncertainty (e.g., how accurate are the acquisition systems? when was the target acquired?). It may, therefore, be possible to represent some of this uncertainty as additional BMS information. In the following sections we refer to "objective uncertainty" simply as "uncertainty".

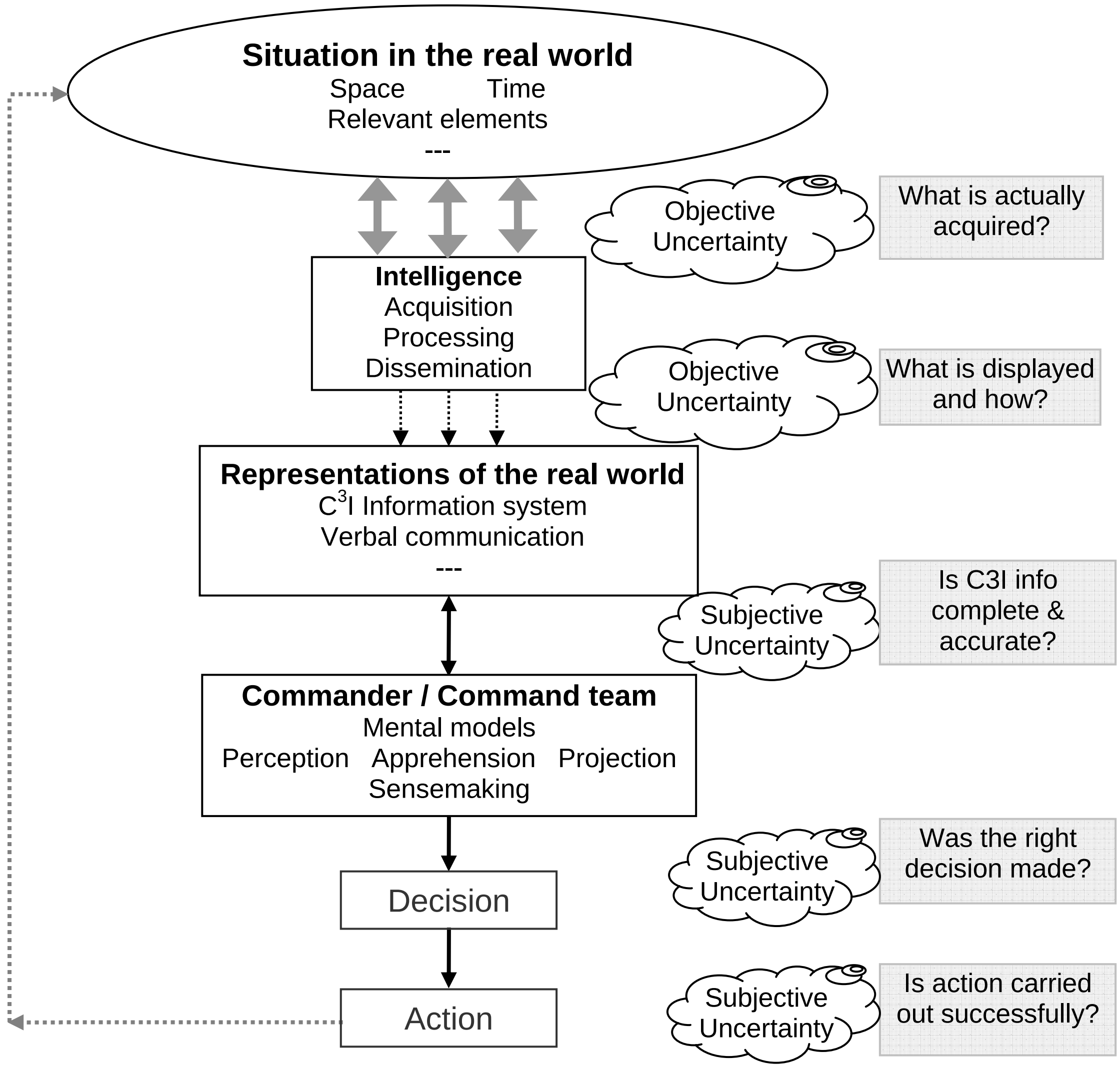


Figure 1: The flow of information from the world to the C^3I system and to the commanders who make decisions and take actions.

Sorting uncertainty

Uncertainty has many definitions, Lipshitz and Strauss (1997) listed 14 different conceptualizations of uncertainty and similar terms (e.g., risk, ambiguity, turbulence, equivocality, conflict). Several definitions refer to the way decision makers conceptualize uncertainty (e.g., Anderson, Deane, Hammond and McClelland, 1981; Lipshitz and Strauss, 1997). Brickner and Lipshitz (2004) proposed to sort it along three main dimensions: Sorting by *source*, by *levels* and by *dimensions* (of the "information world).

Sorting uncertainty by source

Uncertainty can originate from the sources of information, from the information display or from the limitations of the user. The first two categories were defined as objective uncertainty (referred to below as "uncertainty"); whereas the last source was defined as subjective uncertainty.

The combined sources of information that feed C^3I information system or BMS are, inevitably, partial and accuracy-limited. Modern technology enables fairly precise representations of friendly forces (e.g., by distributing their GPS readings). Hostile forces, however, are much more difficult to detect, recognize and understand and are, therefore, the main contributor to BMS uncertainty.

A small C^3I information system display is intended to represent events that take place in a large, dynamic and highly complex real world. Limited display resources contribute to uncertainty (e.g., the scale is several orders of magnitude smaller; height / elevation are represented indirectly, etc.).

Commanders are affected by many more subjective factors that may degrade their decision-making beyond the level imposed by objective uncertainty (e.g., stress, inexperience, lack of attention resources).

Sorting uncertainty by levels of SA

Uncertainty can be sorted according to the three levels of Situation Awareness (SA), perception, comprehension and projection (Endsley, 1995 – see next Section for definition). Generally, C^3I information systems may be quite effective in representing perception (i.e., detect and recognize major features of relevant objects) but less so in representing comprehension (i.e., significance, intentions, and integrative aspects of relevant objects) and projection level (i.e., what will the objects do next, where will they be?).

Sorting by dimensions (of the "information world")

Uncertainty may pertain to any dimension of the "information world": the physical world (e.g., inappropriate representation of heights, outdated maps and photographs, lack of information on navigability), friendly forces (e.g., their exact position and condition) and enemy forces. Obviously, uncertainty with regard to enemy forces may be dominant.

Theoretical background

Recent integrative theoretical concepts may be relevant to the research of uncertainty in C^3I information systems: Situation Awareness (SA), Sensemaking and Naturalistic (Naturalistic) Decision Making (NDM).

Situation Awareness (SA)

Endsley's (1995) definition of SA ("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") is useful in conceptualizing some of the main cognitive processes that are active during the performance of C^3I tasks. Recent research on team SA (e.g., Cooke, Stout and Salas, 2001) expands the applicability of the concept. As stated above, we propose to sort uncertainty by three levels of SA: perception, comprehension and projection.

Sensemaking

The concept of Sensemaking (Leedom, 2001, 2002, 2004; Klein, Phillips, Rall and Peluso, 2004; Klein, Snowden, Chew Lock Pin and Ann, 2007) proposes a wider and more comprehensive view than SA of the cognitive process in individuals, teams and organizations. Klein, *et al.*, (2004) proposed a Data-Frame Theory of Sensemaking. The authors view Sensemaking as a set of processes that is initiated when a person or an organization recognizes the inadequacy of their current understanding of events. Recognition triggers processes that try to resolve the inadequacy by adapting either the frame or the data or both, thereby regaining a state of equilibrium. In addition, Klein, *et al.*, (2004) outline a series of Sensemaking characteristics, several of which seem relevant to the operation of C^3I information systems. Klein, *et al.*, 2007, conducted a pilot study of techniques to improve military Sensemaking, specifically in the area of Cognitive Precision or the “collection and connection of the right dots”, i.e. relevant data. The study was designed to identify obstacles and inherent failures in Sensemaking and cognitive precision in individuals and in groups. Then it assessed the effectiveness of a range of interventions on Sensemaking abilities, specifically cognitive precision. The interventions were tested with seven groups of military and intelligence personnel in the context of two "garden-path[1]" type scenarios (scenarios in which initial "strong," signals are highly misleading with regard to the actual circumstances) – a military planning task and an intelligence assessment task, within which were embedded "weak" but highly relevant signals for detection. The experiment successfully demonstrated many of the obstacles to Sensemaking; and, more importantly, found that the interventions as a whole proved useful in amplifying and identifying weak signals which were otherwise seldom detected.

(Naturalistic) Decision making (NDM)

In the chain of activities of individual and team users of C^3I systems, decision making is the crucial link. Lipshitz, Klein, Orasanu and Salas (2001) reviewed major trends in the history of decision making research and the development of NDM theories. For several reasons, the NDM approach and methodology seems most appropriate for C^3I research.

Proficient decision makers: NDM views the decision making processes of experts as a focal point for research and investigation of decision making.

Field setting: Zsambok and Klein (1997) suggested that "NDM is the way people use their experience to make decisions in a field setting".

Process orientation: NDM models do not attempt to predict which option will be implemented, but describe the cognitive processes of proficient decision makers.

Situation-action matching decision rules: The study of proficient decision makers leads to modeling decision making as matching of a decision to a situation, rather than as choices between alternative decisions to the same situation.

Context bound informal modeling: Proficient decision makers may be limited in their ability to use abstract formal models. NDM models depict what information decision makers actually attend to and which arguments they actually use (Cohen and Freeman, 1996).

[1] Garden-path sentences are relatively complex sentences that are often misinterpreted by readers or listeners e.g., Ferreira, Christianson and Hollingworth, 2001.

Empirical based prescriptions: NDM derives its prescription from descriptive models of expert performance, rather than on soundly based theories (which are non-existent in the case of C^3I systems).

Decision making in uncertainty

Lipshitz and Strauss (1997) defined uncertainty, as "a sense of doubt that blocks or delays action". Using this definition, they identified three principal forms of uncertainty in retrospective reports on decision making under uncertainty: inadequate understanding (a sense of having insufficiently coherent situation awareness), lack of information (a sense of incomplete, ambiguous or unreliable information) and conflicted alternatives (a sense that available alternatives are insufficiently differentiated). In addition Lipshitz and Strauss (1997) identified five principal strategies of coping with uncertainty: reducing uncertainty (e.g., by collecting additional information); assumption-based reasoning (filling gaps in firm knowledge by making assumptions that go beyond directly available data); weighing pros and cons (of at least two competing alternatives); forestalling (developing an appropriate response or response capabilities to anticipate undesirable contingencies); and suppressing uncertainty (e.g., by ignoring it or by relying on unwarranted rationalization). Other researchers have also proposed similar lists of coping strategies (e.g., Klein, 1998).

Based on their research results, Lipshitz and Strauss proposed the RAWFS[2] Heuristic Hypothesis that consists of quasi-normative processes for coping with uncertainty. Decision makers begin by trying to reduce uncertainty by collecting additional information; if this is not feasible, they use assumptions to fill gaps in understanding; they compare the merits of competing alternatives if such alternatives are available. Proficient decision makers may retain a back-up alternative to guard against undesirable contingencies or suppression (denial, distortion of undesirable information) may be used as a last resort. This model is compatible with various naturalistic decision-making models (Klein, 1998; Lipshitz, Klein, Orasanu and Salas, 2001).

[2] RAWFS - Reduction, Assumption-based reasoning, Weighing pros and cons, Forestalling, and Suppression.

One issue that is not represented by decision-making models, including the Lipshitz and Straus (1997) model, is the level of awareness as to uncertainty: does the operator know whether the available / presented information represents high or low levels of uncertainty? The first four coping strategies of the RAWFS model seem to assume that the operator is aware of the level of uncertainty and seeks ways of coping with it, whereas, the fifth strategy assumes that uncertainty is somehow ignored or suppressed. In reality, however, the selection of coping strategies and the resulting decisions may be affected by the operator's awareness of uncertainty. If an operator is totally unaware of the level of uncertainty he or she may act as if they had consciously resorted to the suppression strategy. If, however, the operator is aware of uncertainty he or she may choose to cope through one of the other strategies. This issue can be viewed in terms of the knowledge-driven approach, which argues that decision making in general is determined by operators' knowledge driven strategies, namely, action arguments that describe how decision makers manipulate domain specific parameters in order to achieve a certain goal. From a different perspective, one may ask first, how to enhance the awareness to existing uncertainty and secondly, how to reduce the gaps between actual and perceived quality of representations (displays) of the real world.

Uncertainty in information systems in general and C^3I in particular was observed by several researchers. MacEachren (1992) discusses the issue of map uncertainty. More recently, Harrower (2003) published a review under the title "Representing Uncertainty: Does it Help People Make Better Decisions?" that surveys uncertainty representation in Geographic Information Systems (GIS). The author concludes that in general the answer to the question is positive, however, that more research is still needed. Thomson, Hetzler, MacEachren, Gahegan and Pavel (2005) proposed a typology for visualizing uncertainty especially in the context of intelligence information.

Summers, Jones and Flo (2005) proposed a visualization technique for C^3I SA information that includes uncertainty representations. The system underwent subjective evaluations by SMEs.

Pfautz, Fouse, Farry, Bisantz and Roth (2007) and Pfautz, Roth, Bisantz, Thomas-Meyers, Llinas and Fouse (2006) performed a comprehensive study on the representing of information to support C2 decision making. The study included a literature survey, cognitive task analysis and various evaluation phases. The study developed and evaluated various techniques for visualization enhancement. One of the main conclusions of the authors is that representing uncertainty is not enough; rather, it is necessary to adapt a comprehensive meta-data and meta-information approach. Pfautz *et al.*, (2007, 2006) ran experiments in which they validated the potential applicability of various visualization techniques. They reported that saturation, brightness, and transparency all map naturally to probability and age (of the information) assessments, and are orderable, while hue does not map naturally and is not orderable; effects differ across individuals; and the color difference of the stimulus to the surrounding background has a significant effect and can be used for encoding.

Bisantz, Kesevadas, Scott, Lee, Basapur, Bhide, Sharma and Roth (2002) proposed a comprehensive method for the joint operation representation of tactical information, including the representation of some important aspects of uncertainty. Their positive evaluation of the value of more comprehensive visualization of tactical information is based on a literature survey and on cognitive task analysis.

St. John, Callan, Proctor and Holste (2000), performed two experiments in which Marine Corps commanders were presented with maps and written descriptions of tactical situations with and without uncertainty representation of enemy intent. They concluded that experienced commanders were not affected by the representation; less experienced commanders, however, were likely to wait before acting when uncertainty was high. Kobus, Proctor, and Holste (2000) presented commanders with geographical and tactical information and asked them to prepare a battle plan. They found that under uncertainty, experienced commanders took more time than novices to complete situation assessment processes; however, given the completed assessment, the experienced commanders finished the operational plan quicker and more efficiently than the novices.

LeBlanc and Summers (2007) addressed another aspect of uncertainty representation. One of the difficult aspects of uncertainty representation is clutter; BMS systems tend to become overloaded. The representation of tactical BMS information depends on map scales: the higher the scale, the more information has to fit into the same display area.

Inevitably, there is a tradeoff between the feasible number of displayed entities and the level of detail of each entity. The representation of uncertainty may exacerbate this problem by adding even more information to be displayed.

Preparatory research phases

During the first stages of the present research program, the research team participated in two large scale experiments, a Battle Lab simulation experiment and a field experiment.

The results of these experiments provided valuable insights into some of the issues that were in the focal point of the current research program. Important lessons were learned about gaps between commanders' mental models and BMS information representation, sources of workload, and individual and team SA. Lessons learned provided insight to the preparation of the test-bed of the present simulation experiment. Specifically, real sources of uncertainty in BMS were identified and some of them were used as inputs in the experiment.

The simulation and field experiments and main results are presented in Appendix 3

Research Hypotheses

The general research question is whether the representation of uncertainty on a BMS may enhance various aspects of performance and information processing.

- Can representation of identified uncertainty of battlefield information enhance the decision making performance of commander in a C^2 mission? (Brickner and Lipshitz, 2004)
- Can it affect the nature of coping strategies? (Lipshitz and Strauss, 1997)
- Will uncertainty information affect SA and if so in what respects? (Endsley, 1995)
- Will uncertainty representation affect Sensemaking in terms of the Data-Frame theory? (Klein *et al.*, 2004)

Method

The main objective of the present research program is to investigate the effects of various methods of explicit representation of objective uncertainty on Decision Making processes and strategies, SA and Sensemaking, in a command and control environment. These issues are investigated in a simulated battle environment. The challenge was to create an experimental setup that is both realistic and well-controlled and yields as many quantitative performance results as possible. For that purpose a unique experimental method was developed.

Overview of the experimental method

The experiment is based on a series of experimental scenarios that take place in a simulated urban area (based on an actual town). The scenarios, in general, represent a low intensity battlefield. The blue forces consist of one company operating as part of a battalion. Each experimental trial consists of one main mission (e.g., move through the urban area to a designated location and capture a suspected terrorist, no later than the zero-hour). The mission commander is located in a command post and controls the battle through the BMS only (Figure 2). The commander receives operational orders and a battle plan that specify the goals of the mission, the forces at his disposal, advancement routes, expected threats, zero-hour, etc. (See detailed method below and Appendix 1).

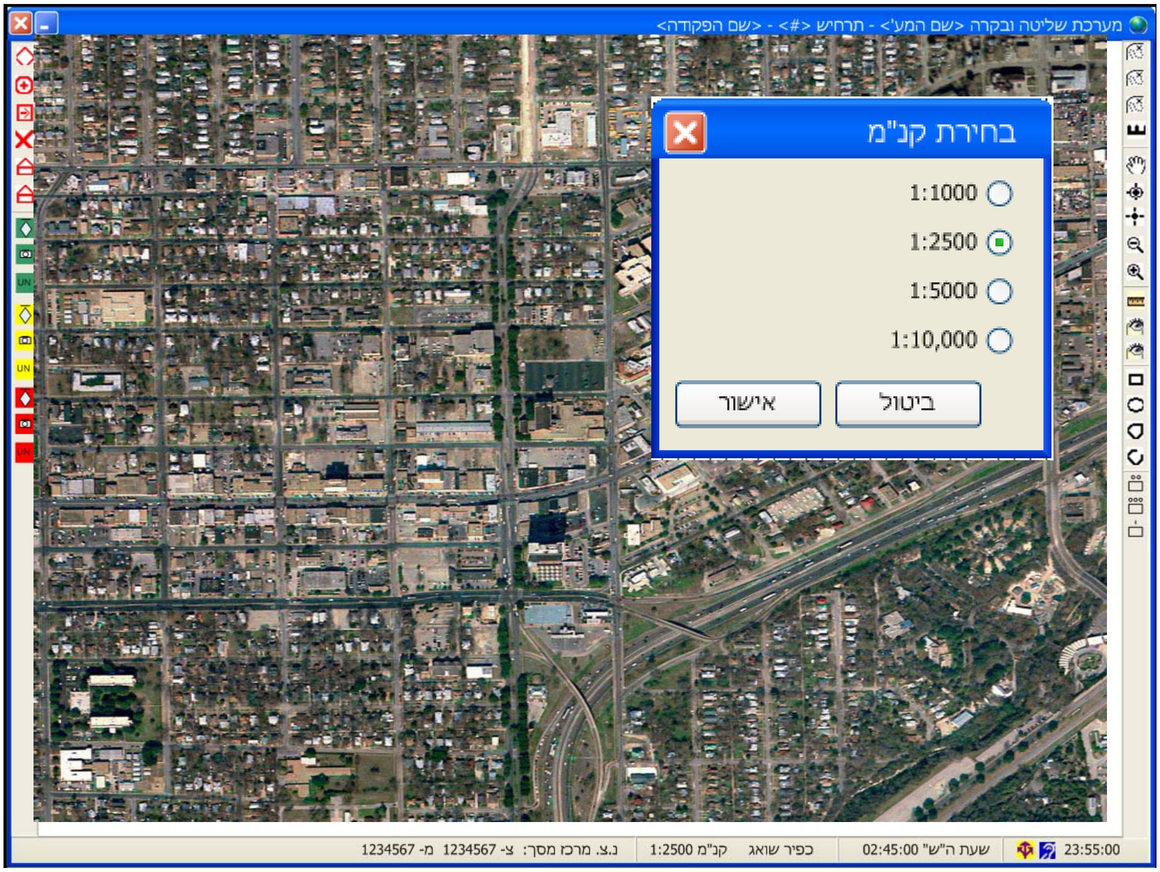


Figure 2: The user interface with an open dialogue box (the User Interface is in Hebrew). In the title bar the name of the system and of the current scenario are displayed. The open window on the map provides selection of various map scales. The status bar (bottom) presents (from right to left) the current scenario time; zero-hour; name and scale of map; and coordinates of a selected object or of the center of the screen (when no object is selected).

In an open simulation environment the commander is free to make decisions at any moment. As a result, scenario development is bound to diverge and evolve differently at each run. In such a variable and unpredictable environment it is practically impossible to extract quantitative measures. To solve this difficulty a unique methodology was developed. The commanders' control over the scenario was limited to "decision points". The scenario is controlled by the computer until a predefined point is reached in which the commander is required to make a decision. Each decision consists of two stages, first the commander has to decide whether or not he wishes to receive more information (e.g., from an unmanned aerial vehicle [UAV]) and, secondly, he has to select a mode of action. Both decision phases are forced choice, i.e., the commander has to select between predefined alternatives (Appendix 1). Each decision generates a predefined result: the request for additional information may or may no yield useful information and the selected action path may lead to favorable or unfavorable operational results. The request for additional information has a price, e.g., the UAV make take time to get to the point of interest and provide the information. In addition, the operational action decision has a price: it may result in operational success (e.g., smooth, eventless passage) or failure (e.g., casualties, unnecessary engagement with hostile forces, lost time). However, at the end of the decision point all forces end up in the same position, regardless of the selected decisions; e.g., if the decision resulted in casualties, personnel was supplemented by reinforcement. This somewhat artificial technique prevents the buildup of variability between subjects resulting from the selected decision(s). Each scenario contains five such decision points

The commander was requested to complete the mission as close as possible to a predefined zero-hour. Actual performance time was affected by requests for additional information (it took time to receive the information) and by the decision taken (usually better decisions produced more rapid performance).

The commander also has several additional tasks. He is asked read and respond to communications (presented as written announcements) and also to respond to various events in the scene (e.g., new threats, specific movements of uninvolved forces). At two or three points in each scenario, the scenario is frozen the commander is asked to answer some SA questions based on SAGAT (Endsley, 2000). At the end of each experiment the commander undergoes in-depth debriefing that, among other objectives tries to capture Sensemaking processes. (See next Sections for a detailed description).

The BMS represents outside world events at various levels of accuracy and comprehensiveness. SMEs that are not exposed to uncertainty representation have to figure out the real situation in the conventional manner. SMEs that are exposed to uncertainty representation receive some additional information that may or may not aid them in making the right decisions. The representation (yes / no) of uncertainty is the main independent variable of this experiment.

Subjects (SME)

Sixteen SMEs participated in the experiment. Subjects were randomly assigned to the experimental or the control group, eight subjects in each.

Subjects ranked from Captain to Lieutenant Colonel, age range was 26-38. All subjects were male and had operational experience as company commanders, two subjects were presently reserve deputy battalion commanders and two were reserve battalion commanders. Ten of the subjects were infantry commanders and the others were tank, engineering or artillery commanders.

Twelve out of the 16 subjects had operational experience with BMS systems. Seven of them had experience or acquaintance with more than one BMS system.

Apparatus

The experiment is conducted in the BatLab which is the major research facility of the Israel Ground Forces (see Appendix 4 for a detailed description).

The experimental setup, including the BMS, is not standard and was developed especially for the present research program. The experimental scenarios were generated by the scenario generator and ran in the background. Their representation on the BMS was presented to the SME on a 17" LCD monitor.

The BMS represented the battlefield overlaid on a detailed aerial photo. Basic map functions where performed with the mouse and the keyboard (Figure 2).

- Scale: Zoom in / out provided scales in the range of 1:1,000-1:10,000.
- Enlarge selected area: a rectangle could be drawn; the selected area would then be enlarged to full window size.
- Distance measurement: the distance between each two points can be measured on the map.
- Information on objects: additional information on objects (e.g., full identity, affiliation, location altitude) can be received by clicking on the object with the right mouse key.

Battlefield information: Layers of battlefield information include the blue forces, red forces, uninvolved (black) and mission plans.

Accuracy and uncertainty: The comprehensiveness and accuracy of BMS information was varied to create realistic types and levels of uncertainty.

Recordings: Both voice and video were recorded for debriefing.

Scenarios

The experiment included six experimental and two training scenarios. Each scenario lasted 30-40 minutes. Each scenario contained five, forced-choice, decision points as described below.

All scenarios take place in a three dimensional (3D) simulation of a real town, built in a mountainous area. Each scenario had a detailed script that specified the chain of events (Appendix 1). Usually, the termination of one phase served as the trigger for the onset of the next phase. Appendix 1 presents a detailed example of one of the scenario scripts.

Missions include: capturing a suspect; locating and destroying an explosive lab; rescuing a downed helicopter crew; setting an ambush for a terrorist group; surveying an area for threats in preparation for another mission; and raiding the headquarters of a terrorist organization.

Forces

During the present stage of research the blue force consisted of an extended infantry company, supported by additional forces: snipers, tanks, engineering forces and various intelligence acquisition devices. The company operates as part of a battalion. Red forces included various types of guerilla forces: gunman, snipers, anti-tank unit, explosive discharges, obstacles, etc. Neutral forces included police, UN, press and media. Uninvolved forces included civilians.

As far as possible, the various entities are represented by standard tactical symbols, excluding the representation of uncertainty which is new and unique (Appendix 2).

Each object of each type has sets of defined features; first, there are the "real" features of the object in the world; secondly, there is its representation on the BMS including: type, identification accuracy, location accuracy, movement representation, information update rates, length of display without refresh (i.e., how long and in what manner will information be displayed if it is not updated).

Most of the time, the representation of blue forces on the BMS corresponds fairly accurately to their actual states; sometimes, however, it may become inaccurate, e.g., due to GPS failure. The representation of red forces is generally much less complete and accurate and entails the most uncertainty.

Events

Each scenario starts at the opening position of the operational event. The forces start moving according to plan. All along the scenario SMEs have to attend to various types of events as described below.

Communication: communication was simulated by written messages that popped-up in a window. The message could be relevant (e.g., indicating a forthcoming threat, neutral or irrelevant) and the SMEs would have to read it and close the window with the mouse.

New information: SMEs were asked to respond to the unplanned events on the BMS (e.g., the appearance of a new threat). Because such events could occur in the periphery of the battlefield, SME had to zoom out occasionally in order to detect them.

Monitoring neutral forces: SMEs were required to monitor the movements of neutral forces including police, UN and media. Three perimeters were specified around the force, near, medium and far perimeter. SMEs had to respond selectively each time one of the forces crossed the line between perimeters. The response was performed with the mouse and included an indication of entity and type of event. This too required SMEs to zoom out occasionally and review the periphery of the battlefield.

Decision points

When the blue force reached a predefined point the commander was faced with a dilemma and was required to make a decision. Each scenario contained five such decision points.

Each decision point included two phases. First the commander was asked to decide whether or not to acquire more information (Appendix 1). Additional information could be received from a UAV, a reconnaissance balloon or other sources (forced choice). The main cost of additional information was time and the possible exposure of the blue force; hence, the commander had to evaluate whether or not he really needs additional information and to decide which device had the best potential to provide useful information. In addition the need for information had to be weighed against time remaining until the zero-hour. The acquired information (sometimes useful and sometimes not) was presented in a window.

Next the commander had to make the operational decision by selecting between three or four forced-choice alternatives (Appendix 1). The selected decision was carried out and its outcomes were presented in a window and on the BMS map. Outcomes could be favorable (e.g., proceeding without further events) or unfavorable (e.g., blue casualties, uninvolved casualties, exposure, time loss). At the end of the decision point, all forces, regardless of the commander's decisions, ended up in the same position, except for the scenario time that was calculated individually. Thus, if a decision caused casualties the commander lost points and was informed about it; however his forces were supplemented with reinforcements in order to eliminate the variability that would otherwise emerge. However, if he lost too much time, he would have to cope with the consequences and attempt to make up for the lost time during the rest of the scenario.

Real time and scenario time

In the experiment "scenario time" differs from "real time," as explained below.

Each scenario has its time frame. It starts at a given time and is supposed to end as close as possible to the zero-hour or as fast as possible (depending on instructions for each scenario). Current scenario time and the zero time are presented on the bottom right corner of the BMS display (Figure 2).

The scenario contains several phases that may impose relatively long periods of time without much action (e.g., infantry force movements, waiting for information from the UAV, etc.). To prevent boredom and waste of time, scenario, time was accelerated 5 times faster than real time. However, since some events require real time (primarily, decision making processes), the time during these events was returned to real time.

During events that are external to the flow of the scenario (SAGAT and confidence rating – see below), the scenario clock was stopped.

Overall, a scenario of approximately 30 minutes (real time) represented three to four hours of operational events.

The uncertainty manipulation

All SMEs in the experimental group were exposed to an information display that included partial representations of objective uncertainty. In theory, a wide repertoire of uncertainty dimensions may be used. In the framework of the present experiment only the following categories of uncertainty were represented (Appendix 2).

- Location
- Direction of movement
- Update status
- Identity
- Affiliation

All categories could be applied to both red and blue forces, however, only location-uncertainty was sometimes applied to the blue forces.

Situation awareness

SA is measured two or three times during each scenario using SAGAT (Endsley, 2000). The scenario was frozen and the SME was asked a series of questions regarding the situation. Question types correspond roughly to Endsley's (1995) SA levels of perception, comprehension and projections. Typical questions were:

<u>Perception</u>:

What is the indicated object (indicated on a map without legends).

Which of the following is the explosive discharge (among the neutrally indicated objects on the map)?

Comprehension:

Which of the following objects endangers your unit (on the map, based on type of force and distance)?

How much time remains until the zero-hour?

Projection:

Which force will be first to reach the junction?

Will force A and force B collide?

In addition, SMEs were asked to rate their confidence level for each SA answer on a scale of 1 - 10.

(See Appendix 1 for a detailed example.)

Recording and Debriefing

During the whole sequence of the experiment both audio and visual displays and responses were fully recorded. In addition, the SMEs were encouraged to speak up, explain what they were doing and to make comments. These comments were manually recorded by the experimenter.

At the end of the experiment each SME underwent debriefing, based on a structured interview. In addition to the prepared questions, debriefing was based on the notes of the experimenter and supported, as necessary, by the recordings. We expected to draw Sensemaking insights from the debriefing process.

Data retrieval and the log file

During the experiment all SMEs' responses were recorded in a log file which was then arranged for processing. The main data collected includes the following:

General information:

Date and time; SME personal information; Assigned group (experimental or control)

Current scenario; Scenario time

SME's responses: for each of the following the type of event (whenever applicable) the accuracy and response times are recorded:

Map manipulations (pan, zoom, etc.); Responses to communication; Responses to general events (appearance of a new entity, etc.).

Responses during decision point: additional information selection, the selected decision and response times for each action.

SA responses: selected response, time to respond, confidence level.

Experimental design and procedure

A between subjects design was selected where each SME is assigned to either the experimental (with uncertainty representation) or the control group (without uncertainty representation). This design was selected in order to avoid possible effects of the uncertainty manipulation on control trials.

Each SME received general instruction and was then familiarized with displays and controls. Next he performed two training trials and six experimental trials. Each trial was preceded by a specific operational order. During the trial SMEs could use a tactical symbol chart (either with or without uncertainty representation) to prevent memory lapses. Debriefing took place after the completion of the last scenario.

Fifteen minutes breaks were taken after the two training scenarios and after the third experimental trial.

The overall length of each experiment was 4.5-5 hours, including breaks and debriefing.

Lessons learned from pre-tests

Several pretests were run during the development phases of the experiment. The following are some examples of lessons learned from the pre-tests:

The quickening of the clock was adapted before reaching the present solution (five times acceleration for inactive periods, actual time for decision making, zero for SAGAT and confidence ratings).

We have learned that some SMEs tend to complete the mission as rapidly as possible, even at the cost of ignoring the advantages of getting additional information. To change this conduct we strongly emphasize that missions have to be completed as close as possible to the zero-hour (rather than as early as possible). In addition, zero-hours were adapted to create a balanced time pressure that is expected to affect requests for additional information during decision points. For example, a highly cautious strategy, asking for as much information as possible will result in serious time pressure and may cause missing of the zero-hour. In contrast a hasty strategy, refraining from additional information would have a negative effect on operational decisions without any operational benefit.

Several events requiring SME response were added in order to keep the subject active and busy between decision points, these include greater numbers of all types of (secondary task) events described in the previous Section.

The request to monitor neutral objects' movement was added when it was realized that subjects tend to stay in a zoom-in configuration, focus on close events and ignore the periphery.

The number and nature of uncertainty representations was increased, varied and refined, including location uncertainty regarding blue forces. In addition, the location of symbols on the BMS does not always reflect the accurate position of objects in the simulated "real" world. This discrepancy is sometimes represented and sometimes not (i.e., SMEs face non-represented uncertainty during all phases and in both the control and the experimental condition).

The nature and size of uncertainty representations underwent several changes and adaptations until reaching its final form (Appendix 2).

Results

Six main types of results were analyzed: (a) the effect of the uncertainty manipulation on overall decision making and on individual decision points; (b) requests for additional information and their effects on decision making quality; (c) individual differences; (d) Performance time and the zero-hour (e) effects of SA; (f) subjective debriefing information.

The uncertainty manipulation

Overall results

Each scenario had five decision points, each of which had three alternative actions that were ranked 1 (best) to 3 (worst). Decision quality was based on outcomes (friendly casualties, civilian casualties, time loss, etc.). It was hypothesized that overall decision making will gain from the representation of uncertainty. Table 1 presents the results. For the uncertainty group the second best decision was the most frequent selection (91 out of 240) whereas for the control group the decisions were more evenly distributed. For both the best answer was the least frequent. These results however, are not significant.

Table 1: Frequency of best, medium, worst decisions by experimental group.

Experimental group	Decision quality			Total
	1-best	2	3-worst	
Uncertainty – N	70	91	79	240
percent	29.1%	37.9%	33.0%	100%
Control - N	74	79	87	240
percent	30.8%	33.0%	36.2%	100%
Total - N	144	179	166	480
percent	30.0%	37.3%	34.6%	100%

Individual decision points

In two out of the 30 (6.6%) decision points there was no variability in the answers. In decision points five and 20, all subjects selected the best decision. Obviously these points could not differentiate between experimental conditions (indicating poor selection of alternatives by the experimenters).

In nine out of the 30 decision points there were significant differences between groups. In seven out of these nine points the uncertainty group did better and in two points the control group did better.

Each of these decision points was analyzed in search of explanations; presently, however we cannot offer a general interpretation of the differences.

Response times

The uncertainty manipulation had no consistent effect on response times. Table 2 presents the data, arranged by request for additional information. The differences are not significant.

Table 2: Average time (seconds) to complete a decision; with no additional information, with one source and with two sources of information.

Experimental group	Response time		
	Asking for information		
	None	1 source	2 sources
Uncertainty – seconds (N)	19.2 (171)	45.2 (54)	71.7 (15)
Control – seconds (N)	18.9 (163)	47.5 (70)	58.2 (7)

Request for information

At each decision point the subject had to decide whether to make the decision without additional information or to request additional information from one source or from two sources. Information from two sources could be requested either in advance or after receiving the information from the first source, however, there were no instances of asking for both sources in advance. It should be noted that the information received was useful only in approximately 75 percent of the cases

Frequencies of information requests

The first finding that emerges is that subjects tended not to ask for additional information. Out of a total of 480 decision events (30 decision points X 16 subjects): in 334 cases (69.6%) no information was requested; in 124 cases (25.8%) one item of information was requested; and in 22 cases (4.6%) two items were requested.

Overall, the uncertainty group asked for somewhat more information than the control group (Table 3). The difference is marginally significant (Pearson Chi-Square=5.239, df=2, p=0.073).

Table 3: Asking for information frequency in the experimental and the control group

Experimental group	Asking for information			
	None	1 source	2 sources	Total
Uncertainty group	171	54	15	240
percent	71.3%	22.5%	6.3%	100%
Control group	163	70	7	240
percent	67.9%	29.2%	2.9%	100%
Total	334	124	22	480

To investigate the hypothesis that uncertainty representation might suppress requests for information, we analyzed the asking-for-information results of the uncertainty group only. Within the 240 decision points of the uncertainty group we distinguished between decision points in which uncertainties were actually represented (199 cases) and those in which uncertainty was not represented (41 cases). The frequencies are presented in Table 4 and Figure 3.

The analysis shows that when uncertainty was not represented there was a significantly stronger tendency to ask for information (44.8% versus 25.6% for one or two sources combined). The results are highly significant (Pearson Chi-Square=7.743, df=2, p=0.03).

Table 4: Asking for information frequency in the experimental group, divided into decision points with actual uncertainty representation and decision points without uncertainty representation.

Existing Uncertainty representation	Asking for information			Total
	None	1 source	2 sources	
Represented - count percent	148 74.4%	38 19.1%	13 6.5%	199 100%
Not represented - count percent	23 56.1%	16 39.0%	2 4.9%	41 100%
Total - count percent	171 71.3%	54 22.5%	15 8.3%	240 100%

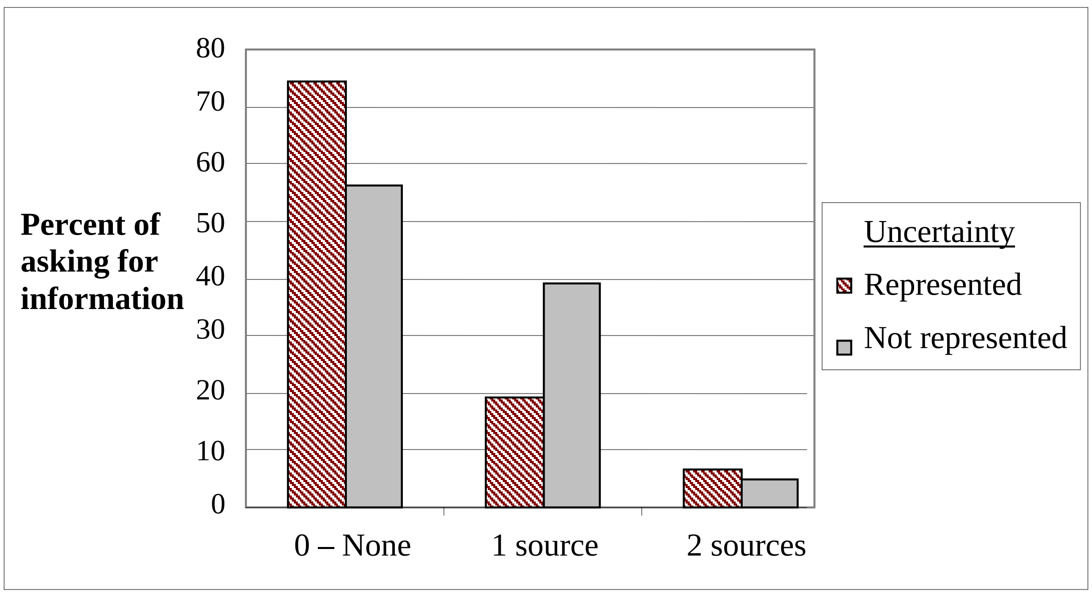


Figure 3: Asking-for-information distribution in the experimental group divided into decision points with actual uncertainty representation and decision points without representation.

Effects of additional information on decision quality

The question is whether or not additional information improved decision quality. Table 5 presents the distribution of information request by decision quality.

Table 5: The distribution of decision quality by information requests. Percents are computed for frequency of request.

Information request	Decision quality			Total
	1-best	2	3-worst	
None	88	126	120	334
percent	26.3%	37.7%	36.0%	100%
1 source	46	38	40	124
percent	37.0%	30.7%	32.3%	100%
2 sources	10	6	6	22
percent	45.4	27.3%	27.3%	100%
Total	144	170	166	480

Note that when no information was requested, the best decision was much less frequent than medium and worst decisions; however, when one or two sources of information were used the best decision became the most frequent one. The results are marginally significant (Pearson Chi-Square = 7.737, df=4, p=0.1).

Order of trials

We checked whether the request for information was affected by trial order, i.e., was the tendency to ask for information reinforced or weakened as the experiment evolved. Even though there is a significant order effect (Pearson Chi-Square=21.406, df=10, p=0.01). It does not seem to be related to the mere order but rather to the nature of the two last scenarios. In the fifth scenario, it was intuitively clear that the mission should be accomplished as soon as possible; accordingly, in only 15 out of 80 decision points was additional information requested. The last scenario involved friendly fire incidents which may have enhanced the tendency to ask for information (35 out of 80 decision points).

Individual differences

In general, there were large individual differences in both decision quality and tendency to request additional information.

Individual Decision quality

The average overall frequency of the best answer was 30 percent. Subjects' performance ranged from 13.3 percent for the weakest subject to 60 percent for the strongest one. The 60 percent success stands out as unique because the three next best performing subjects selected the best answer in only 43.3, 40.0, and 40.0 percent of the cases. Overall individual differences are marginally significant (Pearson Chi-Square=42.229, df=30, p=0.068).

Comparison of the two experimental groups did not yield significant differences and does not reveal any clear patterns.

Individual Requests for information

Requests for additional information varied strongly and were highly significant (Pearson Chi-Square=170.042, df=30, p=0.0001).

One subject used almost all opportunities to get more information and asked for one or two sources in 90 percent of the decision points. Next in frequency were the two subjects who requested information in 53.3 percent of the decision points. On the other end there was one subject who did not ask for any information whatsoever and three other subjects who asked for information in only one out of the 30 decision points.

As indicated above more information tended to yield better answers. Not surprisingly, asking for very little information yielded bad decisions in all cases. The subject who requested information in 90 percent of the decision points did quite well (40 percent best answers). However, both subjects who asked for information 53.3 percent of the time were the poorest and the second poorest decision makers.

Performance time and the zero-hour

Subjects were instructed to complete each mission as close as possible to a specified zero-hour. Subjects could affect time only during decision points by asking or not asking for additional information and by the decision itself which could result in a shorter or longer sequence of events.

The results show that subjects completed most of the missions before the zero hour. Out of 96 cases (16 subjects * 6 scenarios) there were 54 instances of finishing early and 39 instances of finishing late (and 3 missing data points). The overall average was 125 seconds earlier than the zero-hour.

Mission completion time is significantly correlated with rates of asking for additional information (Pearson correlation=-0.308; p=0.003). Subjects who asked for little additional information tended to finish earlier than required; those who asked for much information tended to be late; whereas a balanced use of additional information led to close approximation to the zero-hour.

The correlation between scenario completion time and decision quality was small and marginally significant (Pearson correlation=-0.189; p=0.069).

Being late or early with respect to the zero-hour depended on scenario (Table 6).

Table 6: Average time deviation from the zero-hour by scenario.

Scenario No.	Average deviation time from zero-hour (seconds) (plus=early; minus=late)	No of cases (3 missing cases)
2	-44.9	16
4	-146.0	16
5	+425.7	15
6	+303.5	15
7	-412.8	16
8	+683.9	15
Overall Average	+125.0	93

Note: scenarios 1 and 3 were used for practice.

Situation awareness

All SAGAT questions had forced-choice alternative answers. In general, subjects did quite well on these questions. Given that each question had three or four alternative answers, the correct answer was selected more than half of the time (52.2%).

For the analysis the SAGAT answers were sorted as correct or incorrect. Table 7 presents the overall results for the two experimental groups.

Table 7: Overall SA results for the experimental and the control groups: percent incorrect or correct.

Experimental group	SA answer		Total
	0-incorrect	1-correct	
Uncertainty – N percent	130 46.4%	150 53.6%	280 100%
Control - N percent	135 49.3%	139 50.7%	274 100%
Total - N percent	144 47.8%	179 52.2%	554 100%

The experimental group had a higher rate of correct SA answers than the control group. However, this difference is not statistically significant.

From a total of 36 SAGAT questions seven questions produced significant differences between the two groups. In five questions the uncertainty group did significantly better and in two questions the control group did better.

Learning curves

As explained in the Method section, subjects underwent training; including practice with two complete operational scenarios and then performed six experimental scenarios in a fixed order. The methodological concern of whether decision making performance was affected by order (i.e., was increasingly better performance observed in later trials?) was checked. The general pattern of the results does not reveal any clear order effect. Rates of selection of better or worse decisions varied by scenario but showed no consistent tendency of improvement or degradation over the sequence of trials.

The pattern of results for each scenario was similar for the uncertainty and the control group (i.e., the relative frequency of best, medium and worst decisions was the same) in five out of the six scenarios.

Debriefing

At the end of each experiment (that lasted approximately 4 hours, each subject was asked a series of questions and also encouraged to add comments. The following is a summary of some major points.

Realism of the experimental setup

Most subjects liked the experimental setup and assessed it as a realistic representation of operational challenges, in spite of the restrictions imposed by the experimental setup. They assessed the decision alternatives as representing real battlefield dilemmas. Furthermore, several subjects indicated that such a simulation should be used to train commanders in tactical decision making.

The main reservations voiced by the SMEs with regard to the setup regarded the level of control of the simulated forces. Subjects indicated that company commanders must be in the field with their forces and use the BMS only as an aid. It was therefore unnatural for company commanders to remotely control their forces from a BMS system.

Practically all SA question were rated as relevant, i.e., they sampled information of which the commander should be aware at these points.

Gaps between reality and BMS representation

All subjects knew that a BMS is not a 1:1 representation of reality. They indicated various limitations and restrictions that limit the completeness and accuracy of BMS information. However, when asked what they do about it, the answers varied between: "I am cautious, I try to get more information by radio or other sources,,," and "This is what I have and act upon…".

Asking for additional information

As indicated above, the request for more information varied between 0 and 50 percent of the decision points. Subjects indicated that their decision to ask for more information was based on time consideration (time left to zero-hour). When time permitted, subjects tried to estimate whether information is necessary and whether or not they expect it to be timely and useful. Some subjects were affected by early experience; if some of their initial requests for information yielded no useful information, they tended to avoid requesting information during later scenarios and decision points.

Can the representation of uncertainty help in reality?

All subjects that experienced the representation of uncertainty thought that the representation of uncertainty was a good idea. The main advantage is that it strengthens the awareness as to the limitations of BMS information. On the negative side, subjects indicated that additional information may increase workload and exacerbate display clutter. Therefore, some subjects suggested that uncertainty should be displayed as a layer that can be turned on and off upon request. Other subjects thought that the information might be necessary only for beginners, until they get a strong handle on the uncertain nature of BMS.

It should be noted that these generally positive attitudes are not reflected in the performance results.

At the end of the experiment the uncertainty representations were also shown to subjects of the control group. Most of those subjects also thought that such information could be useful. They too indicated the tendency to perceive a given display as being an accurate representative of reality and, hence, the need to provide useful indications of objective uncertainty to retrain away from this natural tendency.

Discussion

The broad picture that emerges from the results includes some clear cut findings and some less conclusive suggestions. The main research hypothesis was that the representation of uncertainty on the BMS will enhance decision making performance: these manipulations did not reach an overall significant effect. However, it did work for some individual decision points and it was strongly supported by SME statements during debriefing. The clearest findings regard the request for additional information: using available information had significant effects on (improving) decision making quality.

All sixteen SMEs that participated in the experiment were experienced Israeli Ground Forces commanders. All of them had experience as field commanders at the company and / or brigade level. Most but not all had some experience or at least acquaintance with BMS systems. Despite the apparently common background, individual performance levels varied from excellent to very poor. This variability seems to have overshadowed some of the other effects.

The uncertainty manipulation

Overall results

Each of the six experimental scenarios included five decision points, for a total of 30 points. In each decision point the SME had to make a forced choice between three alternative decisions that were ranked 1 (best) to 3 (worst), based on outcomes (friendly casualties, civilian casualties, time loss, etc.). The uncertainty (experimental) group's most frequent selection was the second best decision, whereas the selection distribution of the control was somewhat more evenly divided across the second and third best alternatives. These results however, were not significant. In both groups the best answer was the least frequently chosen, indicating overall poor performance.

Individual decision points

In nine out of the 30 decision points there were significant differences between the experimental and the control group. In seven out of the nine points the uncertainty group did better and in two points the control group did better. Given that two decision points did not yield any variability (indicating inadequate selection of alternative decisions by the experimenters) and that only approximately 70 percent of the uncertainty representations provided useful, non-misleading information, the significant positive effect of the uncertainty manipulation on seven decision points seems to be meaningful and to indicate its potential usefulness. In all of these points uncertainty representation provided useful information. In both negative cases (better performance of the control group) uncertainty information was useless or misleading. Despite a thorough analysis of each decision point we were unable to offer a more general explanation as to why the manipulation had such effect at some decision points and not at others.

Did uncertainty representation affect decision making?

Our first research hypothesis stated that we expect uncertainty representation to have a positive effect on decision making. The actual results are mixed; the manipulation did not yield an overall effect but had a significant effect on some of the individual decision points.

It should be noted that during the preparation of the experiment we were careful to provide balanced scenarios in which actual uncertainty may (~70%) or may not (~30%) be represented; and when represented it may or may not have been useful. Obviously, these precautions must have weakened the effects of uncertainty representation. It may therefore be concluded that uncertainty representation may be helpful under appropriate (i.e., scenario event-dependent) circumstances.

Response times

The uncertainty manipulation had no consistent effect on response times. This may be perceived as a positive outcome, indicating the uncertainty manipulation did not add much workload. It may, alternatively, be indicative of the relatively little attention that some of the subjects allocated to the uncertainty representation.

Request for information

At each decision point the subject had to decide whether to make the decision without additional information or to request additional information from one source or from two sources. Information received was useful only in approximately 75 percent of the cases

Information request frequency

In theory, subjects could be expected to ask for as much information as possible. In practice, however, they made relatively very little use of additional information. Out of a total of 480 cases (30 decision points X 16 subjects), in 334 cases (69.6%) no information was requested, in 124 cases (25.8%) one item of information was requested and in 22 cases (4.6%) two items were requested.

The RAWFS model (Lipshitz and Strauss, 1997), states that when uncertainty is identified, decision makers try to reduce it first by trying to collect more information. Three factors may have suppressed this expected behavior.

- One of the lessons learned from pre-tests was that subjects tended to complete the mission as quickly as possible, refraining from additional information requests in order to save time. To minimize the occurrence of this behavior, subjects were explicitly required to complete the mission as close as possible to the zero-hour (and not as fast as possible) which left them sufficient time to acquire additional information 50-70 percent of the time. In spite of that, the tendency to finish as fast as possible still may have affected performance.
- Additional information was useful only approximately 75 percent of the instances in which it was available. Some subjects, who were disappointed early on, developed mistrust in the information. This behavior is not rational because decision points were independent of each other and because information may or may not be useful in real life as well.

As indicated by our subjects during debriefing, even fairly experienced commanders may fail to identify the gaps between real world information and its representation on the BMS, even though, on a theoretical level they all know that such discrepancies exist. Hence, if subjects did not identify uncertainty they may have been overconfident, not realizing that they actually needed additional information. In terms of RAWFS and based on subjects' debriefing it seems that subjects often employed one of two alternative strategies (instead of asking for more information). First, they used assumptions to fill in identified gaps in information; in particular, uncertainty representation served as such "filler" (see next Section). Secondly, some of the subjects tended to suppress the shortcomings of available information and act as it the picture were clear and certain.

Information requests in the experimental groups

The uncertainty depiction group asked for less information than the control group. This result is counter intuitive because it was expected that uncertainty representation should foster awareness to uncertainty and promote requests for additional information. Furthermore, during debriefing subjects indicated improved awareness to uncertainty as one of the advantages of uncertainty representation.

In order to examine the possibility that uncertainty representation actually suppressed requests for additional information we analyzed information request behavior within the experimental group, comparing decision points in which uncertainty information was available (199 instances across the eight subjects) to decision points without uncertainty information (41 instances across the eight subjects). When uncertainty was not represented, subjects asked for significantly more additional information (44.8% versus 25.6% of the cases). Clearly, the display of uncertainty information interacted with the tendency to ask for additional information. When uncertainty was actually represented it suppressed requests for additional information; whereas when uncertainty was not represented (to the uncertainty group) it drove information requests up to a higher level than in the control group.

Apparently, uncertainty representation does strengthen awareness to BMS uncertainty but is also errantly perceived as some sort of substitute for additional information; allowing subjects to rely on Assumption Based Reasoning (the "A" in RAWFS - Lipshitz and Strauss, 1997) rather than on actual information . Hence when uncertainty is actually represented it suppresses information requests but when it is missing it augments the tendency to request additional information.

Effects of information on decision quality

The findings clearly support the hypothesis that additional information may improve decision making. When no information was requested, the best decision was much less frequent than the medium and worst quality decisions; and when one or two sources of information were used, the best decision became the most frequent one. Clearly, refraining from additional information was counterproductive. In terms of RAWFS (Lipshitz and Strauss, 1997) refraining from requesting additional information was both irrational and counterproductive.

Order and type of trials

We checked the hypothesis that asking for more information may be positively or negatively affected by order. The order effect was found to be significant. However, the most plausible interpretation of the results seems related to the nature of the late scenarios rather than to mere order. The fifth scenario required the rescue of a helicopter team who performed an emergency landing in the hostile area. Even though the zero-hour was specified, it was intuitively clear that this type of mission should be accomplished as fast as possible; accordingly, only in 15 out of 80 decision point events (5 decision points X 16 subjects) was additional information requested. In contrast, the last scenario involved friendly fire incidents; here subjects were more cautious and asked for more information at more than twice the frequency of the personnel recovery scenario (35 out of 80 decision points).

Individual differences

In general, there were large and significant individual differences in both decision quality and tendency to request additional information.

Individual Decision quality

The average overall frequency of the best answer was 30 percent. Subjects' performance ranged from 13.3 percent for the weakest subject to 60 percent for the strongest one. The better performers tended to be more senior commanders (battalion and deputy battalion commander) and had more experience with BMS systems. These findings reflect a good deal of variability and are not based on a consistent relation between performance quality and biographical data.

One subject did outstandingly well and chose the best decision in 60 percent of the cases. The next best three subjects selected the best decision in only 43.3, 40.0, and 40.0 percent of the cases. On the other end of the spectrum, several subjects performed poorly. The four weakest subjects took the best decision in only 13.3, 16.7, 16.7 and 20.0 percent of the cases.

Comparison of individual differences in the two experimental groups did not yield clear patterns or significant differences.

Individual Requests for information

Requests for additional information varied strongly. One subject asked for one or two sources of additional information in 90 percent of the decision points. Next in frequency were two subjects who requested information in 53.3 percent of the decision points. On the other end there was one subject who did not ask for any information whatsoever and three other subjects who asked for information only once across the 30 decision points.

As indicated above more information tended to yield better answers. Not surprisingly, asking for very little information yielded bad decisions in all cases. The subject who requested information in 90 percent of the decision points did quite well (40 percent best answers). However, both subjects who asked for information 53.3 percent of the time were the poorest and the second poorest decision makers. In their cases frequent requests for information seem to reflect lack of self confidence and poor orientation rather than rational handling of information.

In summary, the present research supports previous findings (e.g., Lipshitz and Strauss, 1997) that show the positive relations between information and decision making. The failure of many SMEs to take advantage of available information indicates lack of experience, lack of consciousness and deficient judgment and should be dealt with in training and at command levels. The results of the two subjects who acquired much additional information but performed poorly, indicates that merely acquiring information does not produce good decisions. Additional information must be acquired at the right time and interpreted correctly.

Zero-hour and mission completion

During pre-tests it had been realized that subjects tended to try to complete the missions as fast as possible. The researchers were concerned that hastiness might affect information requests. It was therefore, decided to set a zero-hour for each scenario and require subjects to complete the mission as close as possible to that time. The zero-hour for each scenario was set such that it allowed time for information requests at approximately 50 percent of the decision points. The zero-hour and the current scenario time were displayed in the status bar at the bottom of the BMS monitor (Figure 2).

In practice, subjects' control of the time was very limited because most stages of the scenario were paced by the computer and subjects could affect time only during the decision points. Subjects had a good idea of how long they had to wait until receiving information from a UAV, a balloon, etc.; however, they could not know in advance, how the decision itself might affect time.

Most scenarios (54 out of 93 cases) were completed before the zero-hour and average deviation time was positive (i.e., early). The highest positive deviation (being early) was 1348 seconds and the highest negative deviation (being late) was 1133 seconds. Asking for more information was significantly correlated with finishing the scenario early or late. Additional information required time and therefore subjects who asked for little information tended to be consistently early, those who asked for much information tended to be late and those who were well-balanced finished relatively close to the zero hour.

Different scenarios created different patterns of time deviations. Subjects interpreted the operational situation and acted upon it. In the crashed helicopter team rescue mission (Scenario 8, Table 6) subjects tended to ignore the zero-hour and complete the task as quickly as possible by refraining from asking for additional information, resulting in an average of 683.9 seconds early. On a mission that involved friendly fire (Mission 7, Table 6) subjects tended to be much more cautious, asked for much more additional information and ended the mission 412.8 second late (average).

Situation awareness

SAGAT questions (Endsley, 2000) addressed information in the close vicinity of the blue force as well as peripheral information that was considered relevant. Overall, subjects did quite well and selected the correct answer (out of three or four alternatives) 52.2 percent of the time. The experimental group had a slightly higher rate of correct SA answers (53.6%) than the control group (50.7%). However, these differences were not significant.

From a total of 36 SAGAT questions, seven questions produced significant differences between the two groups. In five questions the uncertainty group did significantly better and in two questions the control group did better. These differences were not correlated with other observed differences.

These results were not surprising because SA questions addressed the overall tactical situation in which uncertainty nuances had little weight. The result may, however, provide a clue to the type of difficulties encountered by the SMEs. If SA score would have been very low, we may have argued that the SME failed to perceive its complexity. However, because the scores were reasonably high we may conclude that the difficulties lie elsewhere. In terms of Ensley's (1995) definition of SA it may be argued that most SMEs passed the *perception* level of SA but failed reaching *comprehension*. This argument is supported by the finding that SMEs, in general, did better on perception level questions (e.g., the identity of objects) than on comprehension questions (e.g., hostility of objects).

Learning curves

Based on the relatively poor overall performance and on subjective impression, we assumed that the subjects were not sufficiently trained. (Recall that subjects underwent two full training scenarios and then six experimental scenarios in a fixed order).

Nevertheless, there was no clear order effect on decision making. Rather, decision making performance was affected by type of scenario rather than by their order (see previous Section). The pattern of results for each scenario was similar in the uncertainty and the control group (i.e., the relative frequency of best, medium and worst decisions) in five out of the six experimental scenarios.

It seems that two training scenarios were sufficient for acquiring the necessary proficiency / technical skills; however, they were not sufficient for acquiring sufficient consciousness to BMS limitations. It seems that much deeper and more extensive training is necessary for actually changing the SMEs' mental model (see Section on Sensemaking below).

Debriefing

At the end of each experiment (that lasted approximately 4 hours), each subject was asked a series of questions was encouraged to add comments.

General appraisal

In general, all subjects expressed positive appraisal of the experiment. Most subjects were highly busy officers who volunteered to participate in the experiment and had difficulties finding a five hour time slot. Nevertheless, once they arrived, they took the time and patience to complete the experiment, make comments and participate in the debriefing session.

Realism of the experimental setup

As indicted in the Results section, the experimental setup, scenarios and tasks received high "grades" for realism, in spite of the restrictions imposed by the experimental setup (forced choice decision points, no control of the commanded force except at decision points). Several subjects indicated that a similar simulation setup should be used to train commanders in BMS usage and in tactical decision making.

With the development of BMS for lower operational command levels, questions regarding the role and the desired location of company-battalion commander have been raised. Should these commanders head their forces into the battlefield? Should they view the world directly or is it better to get an overview via the BMS system? (Schmitt and Klein, 1996). The present experiment was not designed to answer these questions. However, some of the SMEs felt that the experimental situation was not natural / appropriate for the company level. Subjects indicated that company commanders "must" be in the field with their forces and use the BMS only as an aid. It was therefore unnatural for company commanders to control their forces indirectly via a BMS system.

Gaps between reality and BMS representation

In the experiment we got strong support for the notion that commanders may not have real awareness of the gaps between BMS information and reality. On the intellectual level all subjects knew that a BMS is not a 1:1 representation of reality. However, when asked what they do about it - the answers varied between: "I am cautious…", "I try to get more information by radio or other sources…" and "This is what I have and act upon…". In the experiment, the majority of decision points (across subjects) were treated as "This is what I have and act upon…" resulting in many instances of suboptimal decision.

Asking for additional information

As indicated above, at each decision point (five per scenario) subjects had the option to ask for additional information from one or from two sources - prior to making the decision. In the experiment, subjects used relatively little additional information, thereby missing opportunities to make better decisions. Some subjects indicated that for them asking for more information depended on time consideration (time left to zero-hour). When they thought that time permitted, they tried to assess whether information was necessary and whether or not it may be timely and useful. In reality (see "Zero-hour and mission completion" above), time was more strongly affected by the quality of the decision (good decisions usually saved time) than by the time spent waiting for additional information. Debriefing indicates, however, that subjects had no clear awareness of this complicated tradeoff.

Some subjects were affected by early experience; if some of their initial requests for information yielded no useful information they tended to do without information during later scenarios and decision points. Even though decision points were independent of each other, these subjects considered this to be rational behavior. This seems to be a clear example of "Assumption Based Reasoning" (Lipshitz and Strauss, 1997).

Some of the more experienced subjects actually tried to assess the expected usefulness of the information source based on tactical and topographical information (e.g., Could the UAV see into the alley?). This expectation of utility affected the decision to request additional information.

Can the representation of uncertainty help in reality?

All subjects of the experimental group who experienced the representation of uncertainty and most control subjects, who were exposed to uncertainty representation during debriefing, thought that the representation of uncertainty was a good idea. Subjects were asked to recall instances in which uncertainty representation affected their decision. Most of them were unable to recall more than one or two decision points. They thought, however, that representation of uncertainty strengthens the awareness to the limitations of BMS information thereby introducing more caution into the way commanders use BMS. It should be noted that these verbal insights were not supported by actual performance. As we have seen, less additional information was acquired when uncertainty was displayed than when it was not displayed. If the representation of uncertainty does indeed raise the awareness to gaps between BMS information and reality it should have fostered requests for more information and not the other way round.

Some subjects suggested that uncertainty should be displayed as a layer that can be turned on and off upon request. Other subjects thought that it might be necessary only for beginners, until they get a strong handle on the uncertain nature of BMS. Judging by results, at least 10 out of the 16 SME should be considered as "beginners," despite their backgrounds and formal experience.

One clear disadvantage of uncertainty representation is that it adds more information to an already cluttered display (LeBlanc and Summers, 2007). Therefore, as some subjects suggested, uncertainty information should be a selectable (declutterable), rather than a permanent, layer of information.

A perspective on Sensemaking

Most decisions made during the above research were not optimal. To use Klein *et al.,* (2007) terms, they did not do a very good "connecting the dots" job. Sensemaking can be defined as “exploiting information under conditions of uncertainty, complexity and time pressure for awareness, understanding, planning and decision making.” (Klein *et al.,* 2007). Several aspects of Sensemaking are related to team work and are not relevant to the present study; nevertheless, some individual aspects of Sensemaking were identified. On the individual level, most failure causes defined by Klein *et al.,* (2007) may be identified in the present results:

<u>Effect of Mental Models</u>: as revealed during debriefing, some of our subjects did not have a clear notion in regard with the real nature and value of BMS information and tended to

perceive what they see as what really exists in the world. In other words, they employed deficient mental models

Confirmation Bias: (Actively seeking only information that confirms one's hypothesis even in the face of disconfirming evidence). This bias could not be identified in our study because subjects were not given the opportunity to select between alternative sources of information.

Ignoring discrepant information: this kind of behavior could be observed in the experimental uncertainty group where relevant uncertainty information was sometimes overlooked.

Available information was not always exploited: some subjects tended to ignore uncertainty representations and many subjects used only little additional information.

Overconfidence was definitely a significant factor. Clearly some of the younger and less experienced SMEs perceived the situation as simpler than it really was, misinterpreted several of the situations and did not make the best decisions.

For some subjects, the uncertainty representation may be considered as "weak signals". In spite of the emphasis on these symbols during the practice trials some subjects tended not to see or not to connect these "dots".

It would be interesting to investigate the possibility of improving Sensemaking with the techniques proposed by Klein *et al.,* (2007).

Conclusions and Future research

The main purpose of the present research was to investigate the usability of uncertainty representations in BMS systems. SMEs expressed strong support of the idea of representing uncertainty, even though the quantitative results showed a significant positive effect only in approximately a quarter of the decision points. We believe that with more training and increased understanding of BMS capabilities (and limitations) the advantages of uncertainty information may increase. Our conclusion is that such information (when available and reliable) should be available to commanders as an optional layer of information on the BMS. At the present stage we do not think that additional research, in the limited context of objective uncertainty presented herein, may yield much deeper insights.

Another important finding is that available information was underused, resulting in sub-optimal decisions. It is not completely clear why several subjects refrained from requiring available information. Was it due to overconfidence, or perhaps a symptom of the syndrome "men do not ask for direction"? Either way, this kind of behavior was counterproductive and ways of changing it should be devised.

Some individual subjects were excellent decision makers whereas several others did quite poorly. A cognitive task analysis is recommended in order to better the understanding of the basis and the sources of good decision making and impart it with the less proficient commanders.

It is recommended that the existing infrastructure of the IDF BatLab and the system developed for the present research should be expanded and used as a test-bed for team SA and Sensemaking in C^3I systems, in higher level operational environments. In future stages it might be wise to adapt Pfautz *et al.,* (2007, 2006) insight that representing uncertainty is not enough and that it is necessary to adapt a comprehensive meta-data and meta-information approach.

Some potential research issues that have already been identified as relevant and of possible operational benefit include:

- Possible advantages of using 3D C^3I representations as compared to 2D representation (of 3D information)
- Using various perspectives of terrain representations (e.g., top down view versus panoramic view, flexible views controlled by the operator, etc.)
- Advantages and possible drawbacks of combining processed intelligence and tactical information with raw data (e.g., live or recorded video) as a layer on a C^3I system or as a separate source of information.

References

Anderson, B.F., Deane, D.H., Hammond. K.R., and McClelland, G.H. (1981), *Concepts in judgment and decision research: Definitions, sources, interrelations, comments.* New York: Praeger Publishers.

ARNEWS, (2006), *Army assesses new Land Warrior System.* Washington: Army News Service, June 22, 2006.

Bisantz. A. M., Kesevadas, T., Scott, P., Lee, D., Basapur, S., Bhide, P., Sharma, C., and Roth, E. (2002). *Holistic Battlespace Visualization: Advanced Concepts in Information Visualization and Cognitive Studies* (Report). Buffalo, NY: Centre for Multisource Information Fusion.

Brickner, M.S. and Lipshitz, R. (2004). *Pilot Study: System Model of Situation Awareness: "Sensemaking" and Decision Making in Command and Control.* AFRL-HE-WP-TR-2004-0071.

Brickner, M.S. and Sadot-Parag, M. (2005a). Better decision making through representation and reduction of uncertainty in C3I information system, Interim Report no.2, submitted to The European office of Aerospace Research and Development (EOARD), London, England under Contract Number FA8655-04-1-3056.

Brickner, M.S. and Sadot-Parag, M. (2005b). Better decision making through representation and reduction of uncertainty in C3I information system, Interim Report no.3, submitted to The European office of Aerospace Research and Development (EOARD), London, England under Contract Number FA8655-04-1-3056.

Cohen, M.S. and Freeman, J.T. (1996). Thinking naturally about uncertainty. In *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*. (pp. 179-183). Santa Monica, CA.

Cooke, N. J., Stout, R., and Salas, E. (2001). A knowledge elicitation approach to the measurement of team situation awareness. In M. McNeese, E. Salas, and M. R. Endsley (Eds.), *New Trends in Cooperative Activities: Understanding System Dynamics in Complex Environments* (pp. 114-139). Santa Monica, CA: HFES.

Endsley, M. R. (1995). Towards a theory of situation awareness in dynamic systems. *Human Factors,* 37(1), 32-64.

Endsley, M. R. (2000). SAGAT: A methodology for the measurement of situation awareness. In: Endsley, M.R. and Garland, D.J. (Eds.) *Situation Awareness Analysis and Measurement*. Mahwah, NJ: Lawrence Erlbaum Associates.

Ferreira, F., Christianson, K., and Hollingworth, A (2001). Misinterpretations of Garden-Path Sentences: Implications for Models of Sentence Processing and Reanalysis. *Journal of Psycholinguistic Research,* 30(1), 3-20.

Harrower, M. (2003). *Representing uncertainty: Does it help people make better decisions*? UCGIS Workshop: Geospatial Visualization and Knowledge Discovery Workshop, National Conference Center, Landsdowne, VA., Nov. 18-20.

Klein, G. (1998). *Sources of power: How people make decisions*. Cambridge, MA: The MIT Press.

Klein, G., Phillips, J. K., Rall, E.L., and Peluso, D. A. (2004). A data-frame theory of sensemaking. In Hoffman, R., (Ed.), *Expertise out of context: Proceedings of the 6th International Conference on Naturalistic Decision Making* (pp. 113-154). Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G., Snowden, D., Pin, Chew Lock and Teh, C.A. (2007). A sensemaking experiment – Enhanced reasoning techniques to achieve cognitive precision. *ICCRTS 12th International Command and Control Research and Technology Symposium.* Newport, RI, June 19-21.

Kobus, D. A., Proctor, S., and Holste, S. (2001). Effects of experience and uncertainty during dynamic decision making. *International Journal of Industrial Ergonomics,* 28(5), 275-290.

LeBlanc, J. and Summers, V.A. (2007). Retrieval of hidden data - The flip side of decluttering. *ICCRTS 12th International Command and Control Research and Technology Symposium.* Newport, RI, June 19-21.

Leedom D. K. (2001). *Final Report: Sensemaking Symposium*. (Technical Report prepared under contract for Office of Assistant Secretary of Defense for Command, Control, Communications & Intelligence). Vienna, VA: Evidence Based Research. Inc.

Leedom D. K. (2002). *Final Report: Sensemaking Experts Panel Meeting (25-26 June).* Washington DC: Command & Control Research Program.

Leedom D. K. (2004). *The analytic representation of sensemaking and knowledge management within a military C2 organization*. AFRL-HE-WP-TR 2004-0083.

Lipshitz, R. and Strauss, O. (1997). Coping with uncertainty: A naturalistic decision making analysis. *Organizational Behavior and Human Decision Processing*, 69, 149-163.

Lipshitz, R., Klein, G., Orasanu, J., and Salas, E. (2001). Taking stock of naturalistic decision making. *Journal of Behavioral Decision Making*, 14, 331-352.

MacEachren, A.M. (1992). Visualizing uncertain information. *Cartographic Perspective*, 13(Fall), 10-19.

Matthews, M. D. and Shattuck, L. G. (2001). Situation awareness for military ground forces: Current issues and perspectives. In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*. (pp. 351- 355). Santa Monica, CA.

Pfautz, J., Roth, E., Bisantz, A., Thomas-Meyers, G., Llinas, J. and Fouse, A. (2006). The Role of Meta-Information in C2 Decision-Support Systems. *CCRTS, Proceedings of the Command and Control Research and Technology Symposium*. San Diego, CA, June 20-22.

Pfautz, J., Fouse, A., Farry, M., Bisantz, A. and Roth, E. (2007). Representing Meta-Information to Support C2 Decision Making. *ICCRTS 12th International Command and Control Research and Technology Symposium.* Newport, RI, June 19-21.

Schmitt, J. F. and Klein, G. (1996). Fighting the fog: Dealing with battlefield uncertainty. *Marine Corps Gazette*, 80, 62-69.

St. John, M., Callan, J. and Proctor, S., and Holste, S.T. (2000). *Tactical decision making under uncertainty: Experiments I and II* (Technical Report 1821). Arlington, CA: Office of Navel Research.

Summers, V.A., Jones, R.L. and Flo, R. (2005). Increasing situation awareness by visualizing uncertainty. *ICCRTS, 10th International Command and Control Research and Technology Symposium*, McLean, VA, June 13-16.

Thomson, J., Hetzler, B., MacEachren, A., Gahegan, M. and Pavek, M. (2005). A Typology for Visualizing Uncertainty. *Conference on Visualization and Data Analysis*. San Jose, CA, June 16-20.

Zsambok, C.E. and Klein, G. (Eds.) (1997). *Naturalistic Decision Making*. Mahwah, NJ: Lawrence Erlbaum Associates.

Appendix 1: Scenario script and decision points

The following is an example of one of the eight scenarios used in this study.

Operational order

Ten minutes ago an attack helicopter crash landed in urban hostile territory, at approximate location x,y. Its team must be rescued As Soon As Possible by the closest available means.

Outline of friendly forces and missions

Name	**Force components**	**Mission**
A – Platoon Leader	Infantry platoon on two armored vehicles. Engineering unit on engineering armored vehicle.	Move to crash location find crew and take them out to friendly territory.
5A – Patrol Platoon Leader	Patrol unit on two reinforces Hammer vehicles.	Move to crash location find crew and take them out to friendly territory. Provide fire support to A.
Tank – Tank Commander	Tank	Fire and observation support to A
5D - Carmel – Sergeant	Infantry force on command car	Reserve force
Command post - Company Commander	Command post	Command the mission

Method

Day time operation; raid the crash location rescue the team and destroy the remains of the helicopter.

Mission stages.

Outline of main mission stages

Force	Starting position	Stage 1	Stage 2
A	Junction M Moving west on route n	Drive from the east to the estimated location of the helicopter	Locate and rescue the crew to friendly territory.
5A	Not seen on the BMS, on its way to junction M	Drive west to the estimated location of the helicopter	Provide observation and fire support to A
Tank	Not seen on the BMS, on its way to road block R on route n south	Move to observation and support position	Provide observation and fire support to A
Carmel		Remain on site, wait for call	Remain on site, wait for call

Special emphases

Mission top priority

Do not endanger the helicopter crew; avoid fire as far as possible.

Refrain from contact with civilians, avoid civilian casualties.

Mission boundaries

Outlined on the map (Figure 2).

Scenario script

The following tables outline the details of the first part of one experimental scenario (out of eight), including one decision point (out of 5) and one SAGAT Inquiry (out of two in this scenario).

The tables contain the following information:

a. Event: the event in the scenario
b. Trigger: the circumstances that initiate the even. Note the events are triggered by other events rather than by time.
c. Situation in the world: what is the "real" situation in the world in regard with each participating entity?
   - Type of entity
   - Affiliation (to what unit does it belong)
   - Location
   - Movement direction and speed (driving and walking have standard speeds assigned to them).
d. BMS display without uncertainty representation the display of to entity in the BMS
   - Type of symbol
   - Location
e. BMS display with uncertainty representation the display of to entity in the
f. Type of uncertainty – which kind of uncertainty is represented in the specific instance.

Symbols and abbreviations:

a. Upper case letters + numbers: call signs of friendly forces; code names of some locations
b. Lower case letters: code names of some routes;
c. j.nn – code name of junctions
d. Ex. Disch. – explosive discharge; Pl. – Platoon; Id. - identification
e. Local police movements: the movements of local police, which is considered neutral (as are UN and journalist) is governed by separate rules and is not triggered by scenario events.

Part One: Scenario script

Event	Trigger	Situation in the World				BMS Display without uncert. representation		BMS Display with uncert. Represent.	
		Type	Affiliation	Location	Movement direction & speed	Type of symbol	Location on BMS	Type of uncertainty	Param.
A starts moving	Scenario onset	A	Infantry company	On route n	From M to j. 86	Infantry pl.+ engineering	On n	none	
		5A	Company	Out of area	Through M towards j. 86	Patrol unit	none	none	
		Tank	Company	Out of area	South towards police control	Tank unit	none	---	---
		Police patrol	Local police	See Appendix 1	See Appendix 1	Local police patrol		none	
New red objects	A reaches unction 86	A	Company	On n towards j. 84	Driving towards j.86	Infantry pl. + engineering	On n at j.84		---
		Red group	Ex. Disch. unit	north of h.3456	On foot toward j.86	Enemy group + Ex. Disch.	North of h.3456		
5A "starting moving"	A reaches mosque	A	Company	On route N	stopped	Infantry pl. + engineering	On route n at j.86		
		A5	Company	Out of area	Driving towards j.86 through J.M	Patrol unit	none		---
A: "Ident. enemy unit"	A reaches J.86	A	Company	On route N at j.86	Driving towards j.86	Infantry pl. + engineering	On route n		
		5A	Company	On route N	Driving to J.86	Patrol unit	On route n		

Event	Trigger	Situation in the World				BMS Display without uncert. representation		BMS Display with uncert. Represent.	
		Type	**Affiliation**	**Location**	**Movement direction & speed**	**Type of symbol**	**Location on BMS**	**Type of uncertainty**	**Param.**
		nothing	Red			Ex. Disch.	North of 3456		
		Red group	Red	J.89	Moving towards j.89	Enemy group + Ex. Disch.	j.89	are group & Ex.Disch. One or two	Type of relations
Police patrol stops	Patrol reached J.73	Police patrol	Local police	J. 73	Stopped	Local police	j.86		
A: "red group running west"	5a reaches 6677	A	Company	j.86	stopped	Infantry pl. + engineering	j.86		
		5A	Company	On N next to 6677	Driving towards j.86	Patrol unit	On route n next to 6677		
		nothing				Ex. Disch.	North of 3456		
		Ex. Disch.	Red	j.89	Immobile	Ex.Disch.	j.89	Relations between detections	Type of relations
		Red unit	Red	50m west of j.86	Walking from j.89 westward	Enemy group	50m west of j.86		
Decision point	5A reached mosque.								

Decision point no. 1

Issue: How to deal with the suspected explosive discharge?

Additional information (intelligence):

Necessary information	**Device**	**Arrival time**	**Performance time**	**Cost**	**Results**	**BMS update Without uncer.**	**BMS update with uncert.**
Where are the reds / explosive discharges?	UAV	Immediate	2		Identifies object suspected as Ex. Disch. At j.89	none	None
	Balloon	Immediate	1		Identifies object suspected as Ex. Disch. At j.89	none	none
	None	None	None	None	None	None	None

Decision alternatives

Performance alternatives	Actual performance	BMS display & communication	Results	Quality ranking
Continue as planned on northern route	A continues without interference all the way to the school	▪ 5A continues to j.88 where he stops ▪ A: "I am Continuing as planned" ▪ A moves from J.86 south and west until the school, west of 3470	No casualties No exposure No time waste	1
Maneuvering on a route north of the planned route.	A takes the northern route next to 3545 and encounters a gathering continues towards the school only after the crowd moves away	▪ 5 continues to j.88 and stops ▪ A: "taking a northern circumference" ▪ A moves from j.86 north to the route west of 6758 ▪ When arriving at 6758 he takes west and moves a 10 km/h to 3545 ▪ At 3545 the route is block by a crowd ▪ A: wastes 1 minute. Indicates the crowd on the BMS ▪ The crowd moves away and A continues ▪ The crowd symbol disappears from the BMS ▪ A moves west of 3545 until the next junction and from there south to the original route until the school.	No casualties Exposure Time waist	2
Attack the red group	A moves south toward the red group. At j. 89 he encounters the Ex. Disch. Two soldiers are injured. After initial treatment he moves on.	▪ 5A move until j.88 where he stops ▪ A: I am attacking the red unit ▪ A moves to j.89 ▪ At j.89 A reports: "an Ex. Disch exploded next to us, I have to injured soldiers, providing initial treatment: ▪ A appear on BMS as partially disabled. ▪ A moves to the school	Casualties Exposure Time waist	3

Part Two: continuation of scenario events

Event	**Trigger**	**Situation in the World**				**BMS Display without uncertainty representation**		**BMS Display with uncertainty representation**	
		Type	**affiliation**	**Location**	**Movement direction & speed**	**Type of symbol**	**Location on BMS**	**Type of uncertainty**	**parameter**
Zeroing point	A reaches the school next to 3470	A	company	South of 3470	Driving west	Infantry pl. + engineering	South of 3470	Note: at that point all subjects continue from the same position and with the same force, regardless of the decisions they made (except of scenario time).	
		5A	company	j.88	Driving west	Patrol unit	j.88		
		Police patrol	Local police	On route	Driving on route	Local police	On route		
Continuation of scenario									
A: many children run towards me from school and block the way	End of zeroing point	A	Local police	South of 3470	Moving westward a 1km/h	Infantry pl. + engineering	On N		
		5A	Company	j.88	Moving south on M	Patrol unit	j.88		
		Tank	Company	Police control post	Driving south	Tank unit	Police control post		
		Child crowd		West of A	local	Crowd (hundreds)	West of A	Size of crowd	Size of entity
		Police patrol.	Red	j.73	Driving west	Local police	West of j.73		
SAGAT	5A reached the ramp west of 3569								

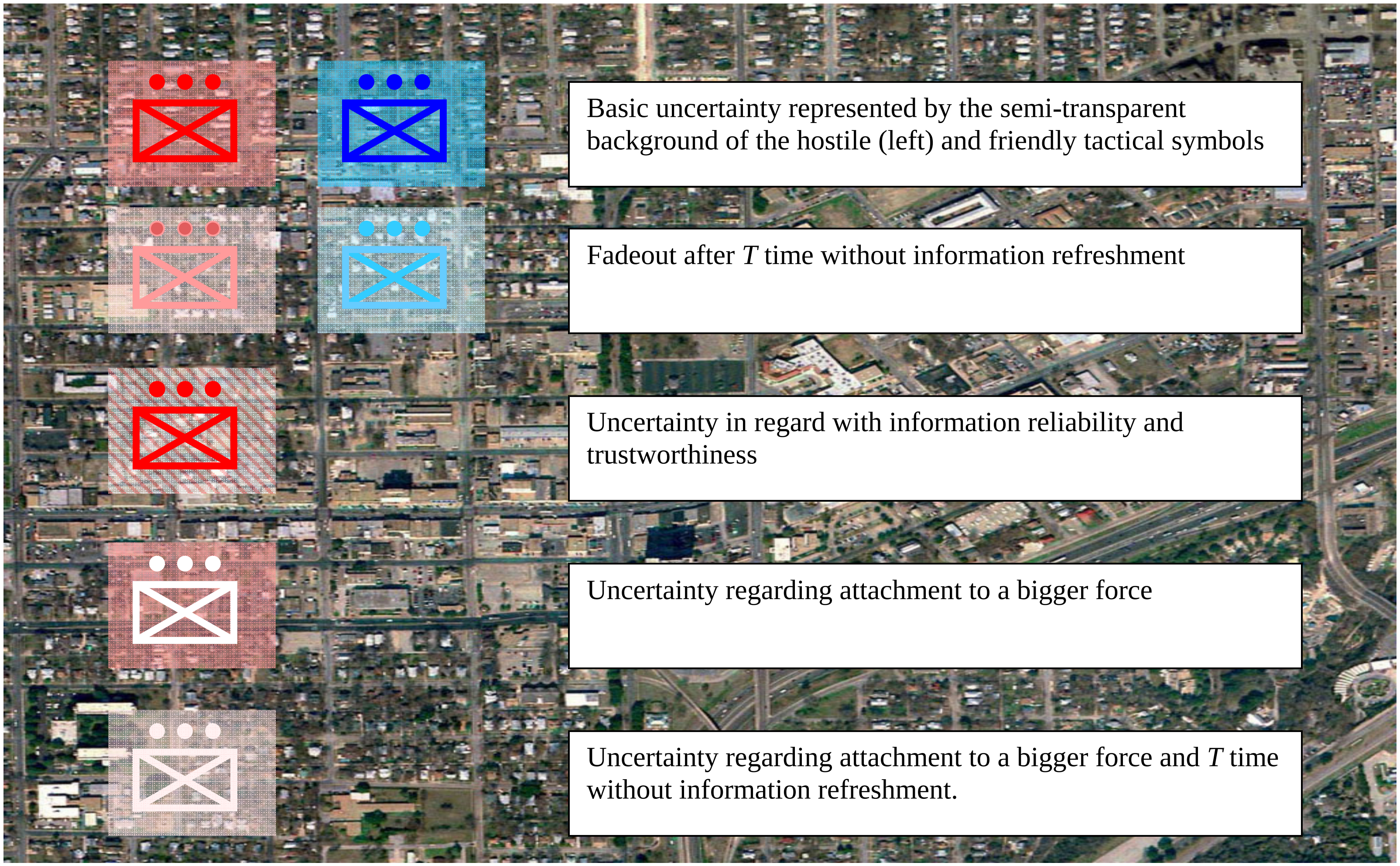
First SA measurement – SAGAT

No.	Map	Question	Alternative answer display	Correct answer	Type of question
1	1;5000 From 490750 to 490250	Where are the pilots	Three alternative positions displayed on the map designated as: a, b c	Unknown	Perception / projection
2	No map	Does the police patrol endanger the crashed pilots?	1. The patrol moves towards the helicopter 2. The patrol moves away from the helicopter 3. The patrol is immobile 4. The patrol is presently not represented on the BMS	1	Comprehension
3	1;5000 From 490750 to 490250	Where did the helicopter crash	Four alternative positions displayed on the map designated as: a, b, c, d	4	Perception

The scenario script continues in this manner trough 3 more decision points and one more SAGAT measurements.
Seven more experimental scenarios and two training scenarios are constructed along the same principles.

Appendix 2: The representation of uncertainty

Uncertainty in general is represented by adding a semi-transparent background to the symbol. The examples below are all on the infantry tactical symbol but may, of course appear with any relevant tactical symbol.



Appendix 3: Simulation and Field preparatory experiments

Research objectives

The Ground Forces of the IDF are testing new concepts and a new force structure for low intensity conflict (LIC) scenarios. To this end a specialized “Low Intensity Combat Tactical Unit (LIC TU)” has been conceived and designated for urban terrain warfare conflicts.

The LIC TU differs from other ground force combat units in three main aspects:

a. The various sub-units composing the force are an organic part of the unit (e.g. engineering forces, armored force).

b. The unit has improved information management abilities based on a common BMS. The BMS provided a moving map display, self and friendly forces location (based on GPS), intelligence (e.g., acquired targets), mission planning capabilities and data links.

c. Some soldiers have autonomous target acquisition devices with which targets may be fed into the BMS.

The structure and operational concept of the LIC TU, was tested in two experiments: a Battle Lab experiment (during October, 2004) and a field experiment (during March, 2005). The objective of the experiments was to consolidate the missions and roles of the LIC TU and examine various aspects of the new unit: its organizational structure, operational methods, the use of newly introduced means of warfare and the integrated battle management using a BMS.

Researchers roles

In both experiments PAMAM's research team had two major roles:

a. To observe and test the research notions developed during the pilot study (Brickner and Lipshitz, 2004) and the initial phase of the present research program (Brickner and Sadot-Parag, 2005 a,b).

b. Members of the research team served as Human Factors specialists for the Israeli Defense Forces (IDF) presenting their conclusions and recommendations for Human Factors improvements and changes to the Israeli Ground Forces.

In practice, the team involvement focused on the following aspects:

- Specify the "information world" of commanders: the team analyzed the information needs and requirements of different commanding levels in order to understand their needs and provide the means for obtaining high levels of SA. The analysis focused on the necessary adaptations of the BMS to the designated LIC TU in urban battle activities.

- Uncertainty representation: The ream investigated the types and levels of uncertainty embedded in the BMS; pinpointed gaps between real world situations and their representations in the BMS and identified their significance.
- Attention and Workload: The research team evaluated workload and resource allocation of commanders during various missions and under different working methods. The relations between working methods, allocation of resources and team work on workload were assessed.
- Human Factors Engineering aspects: The research team participated in the examination of the usability of the different types and installations of the BMS and other devices, in different command environments (rear and front command posts; vehicle and soldier mounted system operation.

Experimental methods

Both experiments simulated fighting scenarios in urban terrain facing terror and guerrilla forces. The subjects were IDF service men and women, each of whom played his / her own current military role. In both experiments participants were equipped with a BMS and supplementary devices, in addition to their personal gear. .

The Battle Lab experiment

Approximately 50 subjects participated in the experiment, representing different roles and ranks (infantry, engineering forces, armored vehicles, snipers, RPV operators, attack helicopter pilots, light artillery and various sensor operators). The red operators were simulated by computer models with optional human intervention. Each of the blue participants viewed an accurate 3D model of a real town on an individual display monitors, from their simulated position in the world. The battle space could be viewed directly, through periscope, IR systems or light intensifiers.

Each participant was equipped with a BMS, displayed on a second monitor, a GPS, speech communication devices, various acquisition devices and different weapon systems. Blue operators could move by foot or on armored vehicles; each operator was able to acquire targets and feed them into the BMS for the common use of all participants. Blue and red operators were represented in the outside world scene and could see each other. On the BMS all blue forces were represented as tactical symbols, whereas, red forces were represented only if a blue force acquired them.

The scenario generator created various scenes and missions that were prepared by Subject Matter Experts (SMEs). The participating forces were required to plan the mission and carry it out. Performance models of existing systems were based on operational analysis and engineering models; and, where such models were not available, task analysis and expert opinions were used. All aspects of performance were recorded. Debriefing took place at the end of each operational scenario and included scenario playback, recognition and analysis of critical events. Qualitative data was collected by trained observers and through questionnaires

The Field experiment

An active infantry battalion supplemented by additional forces (armored vehicles, engineering forces, snipers, UAV operators, sensor operators, and attack helicopter pilots), was recruited for this experiment, which took place in an urban training facility of the IDF. The training area included a small model of an urban civilian settlement (one and two-stories houses, mosque, market etc.), sized approximately 0.5 by 0.7 kilometer.

Control of units' parameters and actions took place in a central control room that gathered all recordable experimental information: blue and red forces position, fire engagements, ammunition inventory, audio, video and data communications. These recordings produced quantitative performance measures (e.g., kill efficiency of weapon systems). Other, qualitative measures were obtained through observations of Subject-Matter-Experts (SMEs) and through interviews and questionnaires. Observations took place throughout all mission stages (planning, briefing, execution and debriefing).

Fire engagements were recorded using a MILES system, computerized fire models indicating hits and misses which were communicated to the central experimental control room which, in turn, delivered the information to the participating forces (e.g., who was "injured", "killed", etc.).

Commanders of the blue forces were equipped with a mobile BMS device. The blue forces were able to observe the battlespace directly using periscopes, IR systems or light intensifiers; or view sensor imagery. Operators were able to designate targets and acquire them into the BMS, operate weapon systems and perform verbal and data communication.

The red operators were simulated by an enemy staging unit that played the roles of enemy forces as well as civilian bystanders.

The battalion engaged in a series of five operational scenarios developed by SMEs.

Observations and relevant Conclusions

The findings described below were compiled from both experiments. The observations were divided along the basic cognitive concepts on which the research is based.

Mental Model

BMS design must match commanders' mental models. The Integration of the various information sources into the BMS (e.g. displaying sensor footprints on the BMS map), is crucial for commanders' success.

Table 8 below summarizes some of the main observations regarding the BMS adequacy to commanders' critical information requirements in the urban battle environment.

The information is sorted based on the analysis of the "information world" of each key role. The example below refers to a Battalion or Company commander.

Table 8: Required and display information on a commander's BMS – conclusions and recommendations.

Role	Type of Info.	Required info.	Displayed info.	Conclusion & recommendations
Battalion / Company commander	**World**			
	Terrain - relief	Detailed terrain, 3D info.	Insufficient scaling	Real zoom-in of up to 1:1000
		Match map to terrain	Inconsistencies, outdated info.	Updated maps, local updating capabilities
		3D terrain representation	Only symbolic 3D (contour lines, shading)	Test the usefulness of perspective 3D displays
	Foliage & human-made objects	Key object identifications	Name (e.g., roads) & Number (e.g., houses) system	Names & numbers invisible at small scale
		Height / floors of buildings	None	Display as label or "tool tip"
		Terrain analysis on relief **and** human-made objects	Partial	Highly necessary for urban activities.
	Friendly forces	Tactical symbols: Location, status	Location	Display status, display minified symbols at small scale. Indicate known sources of uncertainty
		Direction of viewing & pointing	Partial	add
	Enemy forces	Tactical symbols: location, status	Location, partial	Indicate known sources of uncertainty.
		Source of information (who acquired)	Not indicated	Make available as tool tip or pop-up
		Endurance of acquired targets	5 minutes	Should vary base on target type. Should be indicated, e.g., fadeout.
	Civilians	Gatherings, sensitive locations	Partially indicated, often unknown.	Required

Team and Individual SA among the LIC TU commanders

The current BMS design is not supportive enough of the commanders' SA and the shared SA of command teams. The BMS does not provide a sufficiently complete and coherent representation of the current situation. Several weak points affected the quality of the BMS, for example:

- Footprints of sensor devices were not displayed; hence, commander had only a general notion of available sensor information.
- Data communication was slow resulting in insufficiently frequent updates, causing inaccurate display of friend and foe positions. In the dense urban area these relatively small location errors could be highly significant.
- Target acquisition was slow and partial; commanders devised no scheme for effective acquisition. As a result, there was much uncertainty regarding enemy positions.
- Commanders had a strong inclination to rely on sensor imagery rather than on the BMS, consequently they tended to focus on specific events and neglect the big picture.

Despite these weaknesses the BMS was perceived as an important breakthrough. In comparison with the current situation in which communication is primarily verbal, the BMS establishes a common visual language that significantly enhances individual and team SA.

Attention and Workload

In current operations the focus of attention of field commanders (up to the brigade level) is on the real world. The availability of a BMS and multiple sensor imagery creates two types of issues. First, during infantry operations, the operator must carry or wear all components of the BMS; this may affect commanders' mobility. Secondly, their attention must now be divided between several old and new sources. This re-raises dilemmas about to role and desired position of commanders; should commanders be physically with the force, use a close command post or perhaps operate from a rear command center? Each option may have different effects on workload and attention allocation. Our conclusion is that the commander must do whatever necessary to remain on top of things, maintain an overview of the arena, and the control and command of the forces. Hence, he / she should select the position that is expected to yield the best results. Most of the time, the commander should engage in the broader picture and resist the temptation to focus in real-time detailed (e.g., video imagery). Focusing on specific actions should be limited to events of utmost importance were the overall situation is controlled by another team member (e.g., deputy commander).

In the experiments, some incidents of excessive workload resulted from the addition of additional forces (armored vehicles, engineering forces, etc.). The demands of such a multifaceted force, that were novel to the otherwise experienced infantry commander, led to inappropriate teamwork. The commander did not delegate sufficient authority and sometimes failed to allocate tasks and responsibilities to his team members. As a result, he reached peaks of overload while some of his team members may have been idle.

Uncertainty within the BMS

As indicated above the use of BMS enhanced SA and common language. Nevertheless, there were considerable gaps between real-world events and their representation on the BMS, i.e., there were significant levels of uncertainty.

Table 9 below provides a summary of different aspects of uncertain information observed in the BMS. Uncertainty is analyzed along three levels of SA and across four dimensions: completeness, accuracy, up-to-dateness and depth (see detailed definitions in Brickner and Lipshitz, 2004).

Table 9: Identified layers of uncertainty of BMS information.

Information world Dimension	**Uncertainty component**	**Situation Awareness Level**		
		Perception	**Comprehension**	**Projection**
Physical World - Terrain relief	Completeness	Lack of height representation	Partial comprehension by relief	Lack of a comprehensive picture reduces the ability to project future position
	Accuracy	Mismatch between aerial photograph and terrain	Partial comprehension based on terrain analysis	
	Up-to-dateness	Mismatch between aerial photograph and season \ current state	Lack of a comprehensive terrain picture due to an unclear representation of terrain	
	Depth			
Physical World – Foliage & human-made objects (trees, houses)	Completeness	No representation of elevation / stories / height Terrain analysis did not refers to foliage and human-made objects	Comprehending relative height by shading No navigability comprehension	
	Accuracy	Mismatch between aerial photograph and features	Partial comprehension of structure due to lack of 3D representation	Lack of a comprehensive picture reduces the ability to project future position
	Up-to-dateness	New objects not in BMS. Old objects in BMS and not outside		
	Depth			
	Accuracy			
	Up-to-dateness			
	Depth			
Friendly forces	Completeness	Disappearance of forces inside buildings was not simulated in		No direct representation of predicted future state Limited

Information world Dimension	**Uncertainty component**	**Situation Awareness Level**		
		Perception	**Comprehension**	**Projection**
	Accuracy	experiments Location accuracy limitations due to oversized symbols Identification difficulties of overlapping symbols		projection ability from planning stage Slow update rates obstruct projection
	Up-to-dateness	low due to slow update rates	no representation of status, intention etc. (Apart from extermination)	
	Depth			
Enemy forces	Completeness	Comprehensive representation during intelligence gathering (prior to making contact) Very partial picture during combat	Partial identification of objects No identification of patterns or units each object treated independently	No projection capability beyond general assessment of alternative modes of operation
	Accuracy	Accuracy depends on acquiring device		
	Up-to-dateness	Position is not dynamically updated	No representation of position inaccuracy	
	Depth	Source (who acquired) not identified	No representation of Up-to-dateness (e.g., time of acquisition) No representation above position and possible identification (capabilities, status, intentions)	
Neutral & Civilians	Completeness	Partial and general information only most information is not represented	Intuitive understanding	Intuitive projection
	Accuracy			
	Up-to-dateness			
	Depth			

The BMS may create a misleading illusion of complete and accurate battlefield SA. It is important to prevent this risk without crippling the very use of the BMS. Adding uncertainty representations to the BMS (e.g., time of last update, approximate\ estimated location) may reduce the risks of both overconfidence and lack of confidence in the BMS. The commander who is aware of BMS uncertainty may take precautions and use additional means for reducing its impact (e.g., drill down for more information, wait for the completion of update cycles, use voice communication, assess the reliability of information based on source, etc.).

The projection of the near future situation of friendly forces can be improved by incorporating planning-stage information into the BMS display (e.g., mission stages). In contrast the ability to project enemy actions in a LIC urban scenario is practically nonexistent.

Summary

The results of the above simulation and field experiments provided valuable insights to some of the issues that were in the focal point of the current research program. Important lessons were learned about gaps between commanders' mental models and BMS information representation, Sources of workload, individual and team SA. Lessons learned provided insight to the preparation of the test-bed of the present simulation experiment. Specifically, real sources of uncertainty in BMS were identified and some of them were used as inputs in the experiment.

Appendix 4: The Battle Laboratory (BatLab)

Introduction

The Battle Laboratory (BatLab) of the Israeli Ground Forces is a simulation laboratory that is capable of simulating and presenting virtual environments, run operational scenarios and allow operators to perform their tasks in the scenario within the simulated environment and operate a variety of simulated devices. Events as well as performance measures are recorded and can be replayed and analyzed.

BatLab has evolved from the Human Factors Branch in the early 90s and is now part of a center for military research. BatLab's simulation capabilities are based, primarily, on COTS software and hardware.

The laboratory focuses on human-machine systems and has three primary missions:

- To test and specify human-machine systems and user interface designs
- To test operating methods.
- To test Operational Policies and the operational organization of fighting units.

During its first years, BatLab focused primarily on single operators and small groups, in recent years, however, technologies (and experience) enable BatLab to concurrently employ approximately 50 positions. This enables the lab to simulate and test the operation of much larger units (e.g. companies, battalions, command posts, etc.).

Primary features of BatLab

1. Human In the loop: BatLab investigates functions in which humans play a significant part as operators or as commanders.
2. Virtual Environments: Simulations take place in virtual environments.
3. Real time: BatLab simulates operations on a real time base. Simulation runs continuously at the pace of the regular clock. Only marginal events (in terms of the focus of research) may be sped-up to save time (e.g., maintenance times).
4. Demonstration and familiarization: with humans-in–the-loop, real pace simulation. Because it is not feasible to perform scores of runs and replications, the lab does not substitute operational analysis simulation tools. In the preparation processes of experiments, efforts are being made to select the most reasonable parameters, thereby reducing variability. In some cases the number of runs may suffice for statistical significance, whereas, in other cases, results remain qualitative.
5. Employment and integration of devices and weapon systems: the simulation of tested devices and weapon systems operates on the basis of the same simulation devices. It is, therefore, easy to introduce new devices and incorporate them into existing simulation facilities.
6. Flexibility: For the simulation of devices and weapon system it is sufficient to have a good specification of its functionality whereas full engineering

specification may not be necessary. Hence, BatLab can test systems during any phase of their development and elaborate the simulation as the system develops.

7. Short response times: the time required for simulation is a fraction of the time required for actual development. Given the necessary definitions specifications, the lab is capable of rapid preparation and execution of experiments.

Components of BatLab

The basic components of the lab are presented in Figure 4

.

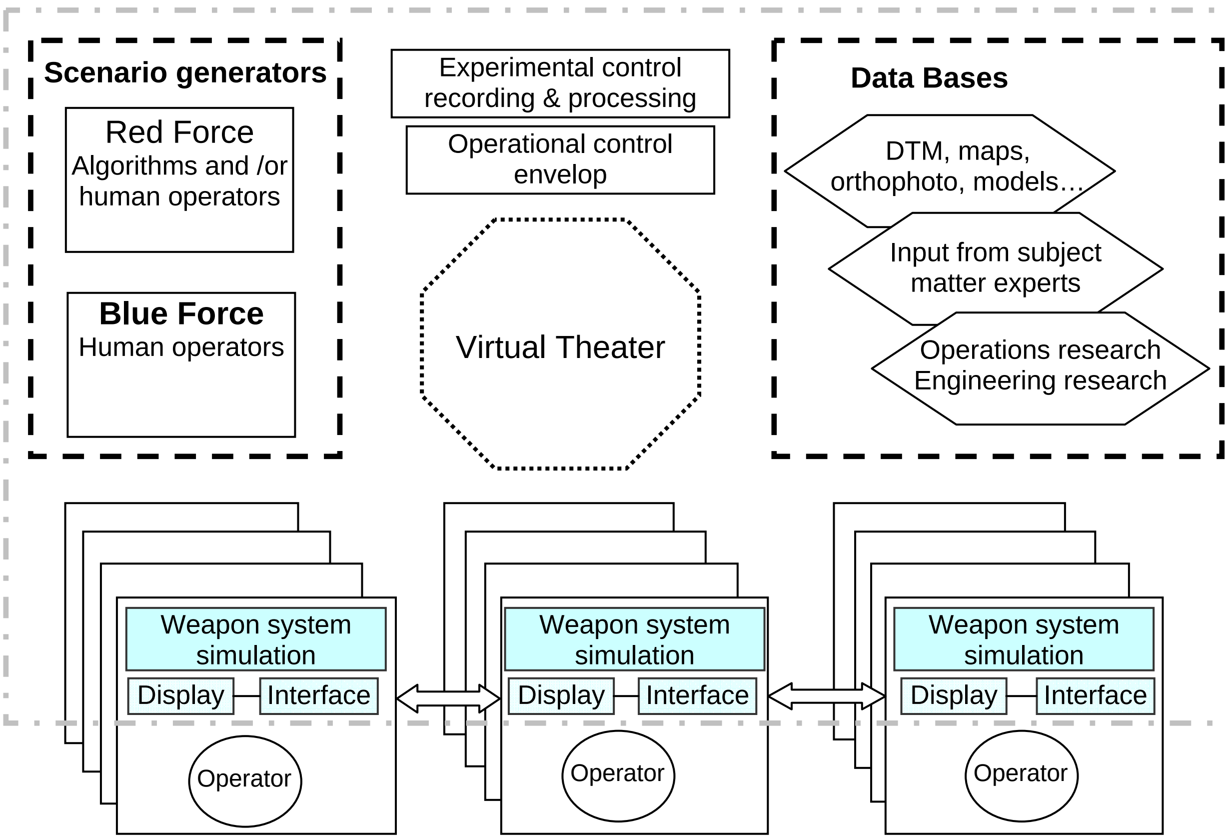


Figure 4: Outline of the basic components of BatLab.

Theoretical Foundations

The theoretical foundations for most BatLab research stem from two main sources. Whenever possible, existing engineering and system operation models are applied and adapted as necessary.

If such models do not yet exist, then the best possible approximation is created with the aid of individuals and teams of subject matter experts (SME).

Outside world representation

BatLab has the necessary component for the simulation of the world, including: maps, aerial photographs, orthophoto, DTM, models of various systems, platforms and terrain features, battlefield effects and atmospheric effects. These enable the creation of 3D representations of the world with 3D objects that can be manipulated in various ways (move, shoot, emit smoke, be hit, etc).

Devices and weapon systems

The simulation of existing systems is based on their engineering and system operation models, whereas, the simulation of future devices is based on SME analyses, including the representation of user interfaces.

Communication between operators comprises speech as well as data communication.

Communication features may include –

- Communication between systems (e.g., and aircraft and a missile).
- Communication between command and control systems within one network or between different networks.

Scenario generator

The scenario generator controls all components that are not controlled by humans during the experiment; for example, the red forces and neighboring blue forces. Hence, the scenario generator is responsible for important components of the "battlefield theater" and contributes to the operators' immersion in the simulated world.

Monitoring and control

Experiments may have two types of monitors or controllers:

Experimental monitoring: the technical control team enables the smooth performance of simulation, repetition of scenarios, last minute changes, etc.

Operational control: The operational control team may provide additional necessary interfaces for the experimental subjects. For example, in a company level experiment the battalion command may be represented not as an integral part of the experiment but as an interface that add realism to the function of the company commander.

Recording and processing

All events in a simulation are recorded and can be replayed and reconstructed. Statistical analysis can be performed on the data, as necessary.

Glossary

2D – Two dimensional
3D – Three dimensional
BatLab - Battle Laboratory
BMS – Battle Management System
C^3I – Command Control Communication and Intelligence
CCIR - Commanders' Critical Information Requirements
COTS - Commercial off the Shelf
DTM – Digital Terrain Mapping
GIS - Geographic Information System
GPS - Global Positioning System
IDF – Israel Defense Forces
LCD – Liquid Crystal Display
LIC - Low Intensity Conflict
NDM – Naturalistic Decision Making
SA – Situation Awareness
SAGAT - Situation Awareness Global Assessment Technique
SME – Subject Matter Expert
TU – Tactical Unit
UAV – Unmanned Aerial Vehicle
UN – United Nations