Cover page

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Better decision making through representation and reduction of uncertainty in C^3I information system

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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
df – Degrees of freedom
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

Abstract

Battle Management Systems (BMS) have enhanced the availability of battlefield information. Yet, commanders may not always be aware of BMS limitations and may consider displayed information as an undivided representation of the world; whereas, in reality BMS information tends to be uncertain (e.g., incomplete, only partially accurate). Some sources of uncertainty may be anticipated and presented to the operator (e.g., information acquisition time). It was hypothesized that displaying this uncertainty may enhance commanders' decision-making.

Two training and six experimental scenarios presented realistic urban battlefield simulations, while maintaining a well controlled experimental setup. Each scenario contained five, forced-choice, decision point. Decisions could be good, medium or bad, based on operational outcomes. Before each decision the operator could opt to ask for additional information (e.g., from an unmanned aerial vehicle [UAV]). Sixteen company or brigade commanders of the Israel Defense Forces were divided into an experimental uncertainty group and a control group for the five hour experiment.

Uncertainty representations did not produce better overall decisions; however, in seven out of 30 decision points it had a significant positive effect. Using additional information significantly improved decisions, nevertheless, several subjects rarely requested any additional information, resulting in poor performance. Subjects rated the experimental setup as realistic and relevant and expressed a desire to be presented with uncertainty information as an optional information layer on BMS.

Introduction

In recent years the technology for acquiring, processing, distributing and displaying battlefield information has been constantly developing. One important consequence of such approach is a much wider distribution of Command, Control, Communication and Intelligence (C^3I) information devices. 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 and maintain high levels of uncertainty. Brickner and Lipshitz (2004) suggested defining "uncertainty" as the gap between reality and the actual knowledge (or situation awareness) of the commander. They 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).

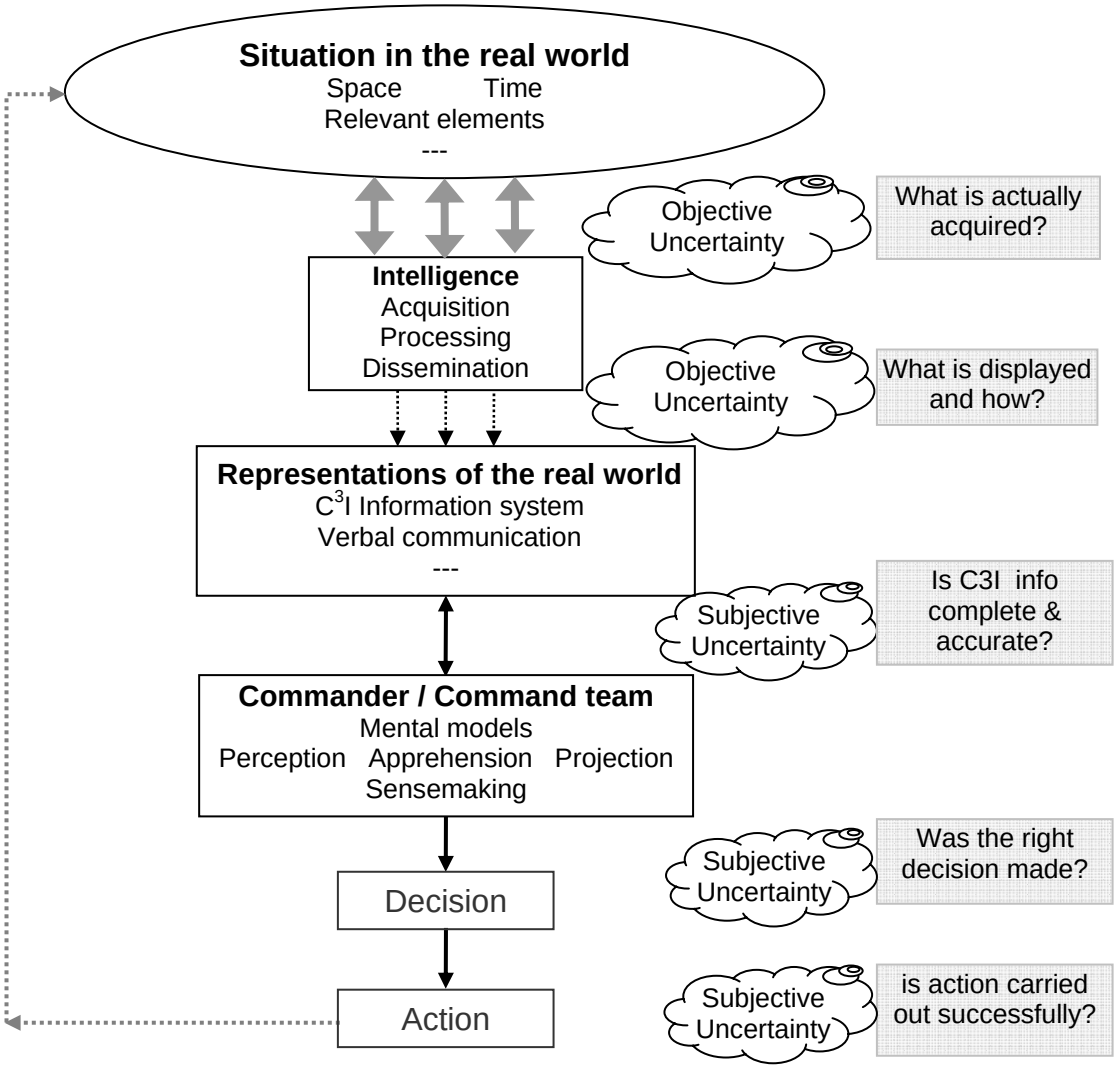

Figure 1: The flow of information from the world to the C^3I system and to the commanders; types and sources of uncertainty.

The present research is about "objective uncertainty" (referred to as "uncertainty" in the following sections). It is argued that the overall system may benefit from displaying known sources of uncertainty (e.g., accuracy of acquisition; time of acquisition).

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 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. SAGAT (Situation Awareness Global Assessment Technique – Endsley, 2000) is a validated SA measurement technique.

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. 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”. 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. 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.

Decision making and uncertainty

In the chain of activities of individual and team users of C^3I systems, decision making is a 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.

Lipshitz and Strauss (1997) defined uncertainty, as "a sense of doubt that blocks or delays action". They identified five principal strategies of coping with uncertainty on which they based 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).

Several researchers acknowledged the potential importance of uncertainty representation. 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 Subject Matter Exterts (SMEs). Pfautz, Farry, Fouse, Bisantz and Roth (2006, 2007) performed a comprehensive study on the representation of information to support C2

[1] Garden-path sentences are relatively complex sentences that are often misinterpreted by readers or listeners e.g., Ferreira, Christianson and Hollingworth, 2004.
[2] RAWFS - Reduction, Assumption-based reasoning, Weighing pros and cons, Forestalling, and Suppression.

decision making. The researchers developed and evaluated various visualization enhancement techniques. They concluded that representing uncertainty is not enough; rather, a comprehensive meta-data and meta-information approach should be adopted. Bisantz, Kesevadas, Scott, Lee, Basapur, Bhide and Sharma (2002) proposed a comprehensive method for the presentation of tactical information, including uncertainty representation. Their evaluation of comprehensive visualization of tactical information is based on a literature survey and on cognitive task analysis. John, Callan, Proto and Holate (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 uncertainty representation; less experienced commanders, however, were likely to wait before acting when uncertainty was high. Kobus, Proctor, Bank and Holste (2000) presented commanders with geographical and tactical information and asked them to prepare a battle plan. 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.

LeBlank and Summers (2007) addressed the clutter issue and argued that Uncertainty representation may exacerbate the problem by adding even more displayed information.

Research Hypotheses

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

- Can representation uncertainty 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? (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, on SA and on Sensemaking, in a command and control environment. A unique experimental method was developed to create an experimental setup that is both realistic and well-controlled and which may yield several quantitative performance measures.

Overview of the experimental method

The experiment is based on a series of operational scenarios that take place in a simulated urban area. The scenarios represented a low intensity battlefield. The Blue forces consisted of one company operating as part of a battalion. Each experimental trial involved one main mission (e.g., move through the urban area and capture a suspected terrorist, as close as possible to the zero-hour). The mission commander was located in a command post and controlled the battle through the BMS only (Figure 2). The commander received operational orders and a battle plan that specified mission goals, forces at his disposal, advancement routes, expected threats, zero-hour, etc. (Appendix 1).

To overcome the buildup of variability that is inevitable in regular simulation techniques, a unique methodology was developed. The commanders' control over the scenario was limited to "decision points". The scenario was controlled by the computer until a predefined point was reached in which the commander was required to make a decision. Each decision consisted of two stages, first the commander had to decide whether or not he wishes to receive more information (e.g., from an UAV); secondly, he had to select one of three modes of action. Both decision phases were forced choice, i.e., the commander had to select between predefined alternatives (Appendix 1). Each decision generated a predefined result: the request for additional information might or might not yield useful information and the selected action path might lead to good, medium or bad operational results (e.g., smooth passage versus casualties, unnecessary engagement with hostile forces, lost time). The price paid for requesting additional information was waiting time. At the end each decision point all forces ended up in the same position,

regardless of the results of their selected decisions; e.g., if the decision resulted in casualties, personnel were supplemented by reinforcement. This somewhat artificial technique prevents the buildup of between-subject variability due to selected decisions. 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 was asked to read and respond to written communications and to respond to various events in the scene (e.g., new threats, specific movements of uninvolved forces). At two or three points the scenario was frozen and the commander was asked some SA questions based on SAGAT (Endsley, 2000). At the end of each experiment the commanders underwent in-depth debriefing.

The BMS (Figure 2) represented tactical information at various levels of accuracy and comprehensiveness. Control group subjects had to figure out the real situation in the conventional manner, whereas the experimental group was exposed to uncertainty representation that might or might not have aided them in making the right decisions. Uncertainty representation (yes / no) was the independent variable of this experiment.

Subject Matter Experts (SMEs)

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.

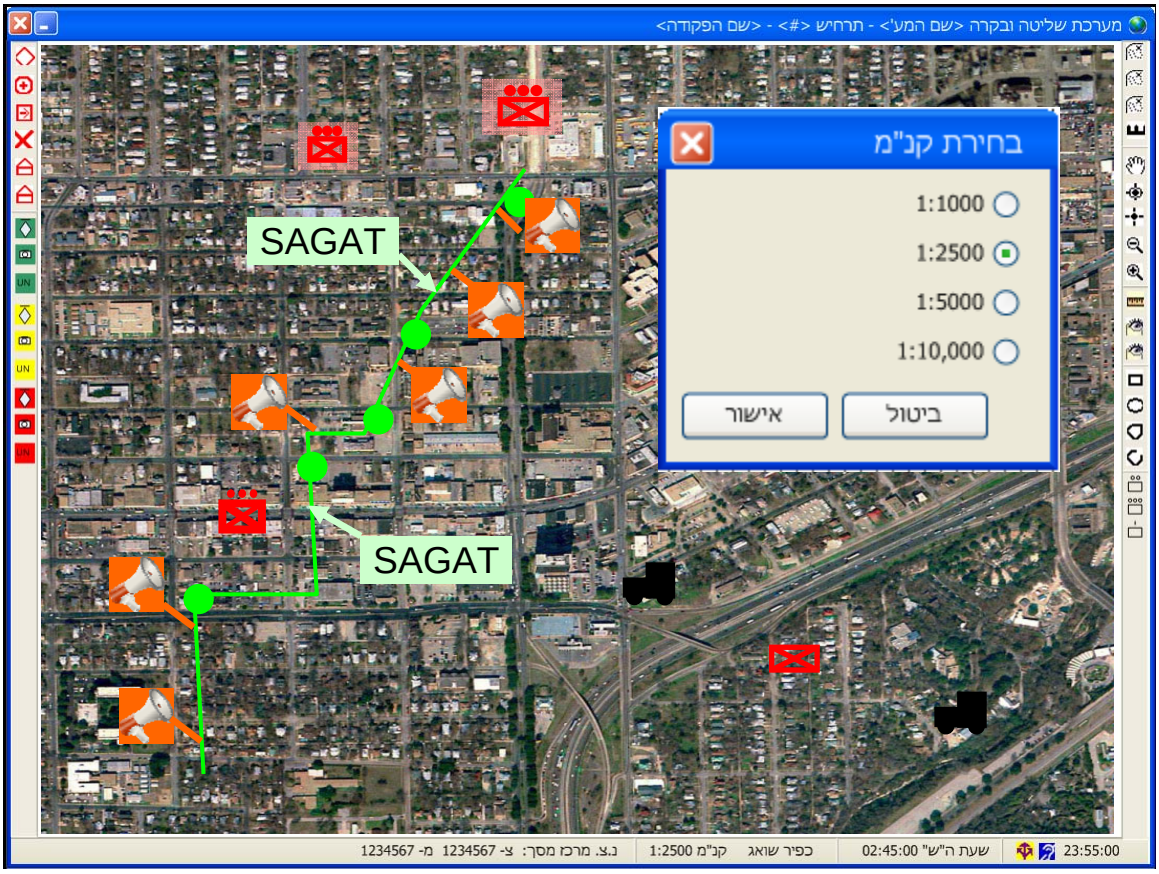

Figure 2: The user interface with an open dialogue box (the User Interface is in Hebrew). In the title bar the name of the system and of the current scenario are displayed. The open window on the map provides selection of various map scales. The status bar (bottom) presents (right to left) the current scenario time; zero-hour; name and scale of map; and coordinates of a selected object. The tactical symbols were presented on the map.

The other displayed elements were not an integral part of the display. They are displayed as an illustration of the experimental method. The Green line is the advancement line of the blue force. Each full green circle represents a decision point. The loudspeaker icon represents incoming messages and the SAGAT label indicates the position in which SA measures were made.

Apparatus

The experiment is conducted in the Battle Laboratory (BatLab) which is the major research facility of the Israel Ground Forces. The experimental setup 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.

BMS map and functions: The BMS represented the battlefield on a detailed aerial photo (Figure 2). Operators could perform basic functions including: panning; zooming in the range of 1:1,000-1:10,000; enlarge a selected area; measure distances and receive additional information on objects.

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

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 took place in a real, mountainous town. Each scenario had a detailed script that specified the chain of events (Appendix 1). Missions included: capturing a suspect; locating and destroying an explosives 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 snipers, tanks, engineering forces and various intelligence acquisition devices. 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.

Standard tactical symbols were used for all entities. Additions to the symbols were made for uncertainty representation (Appendix 2).

Most of the time, the representation of Blue forces on the BMS corresponds fairly accurately to their "actual" states in the simulated world. The representation of Red forces was generally much less complete and accurate and entailed the most uncertainty.

Events

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

Communication: communication was simulated by written messages that popped-up in a window. Some messages were relevant to the task while other were just distracters.

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 and report the movements of neutral forces including police, UN and media.

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. Next the commander had to make the operational action decision by selecting between three 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 was informed about it but his forces were supplemented

with reinforcements in order to eliminate the between subjects 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" differed from "real time,". Each scenario had its time frame. It started at a given time and was supposed to end as close as possible to the zero-hour. Current scenario time and the zero time were presented on the bottom right corner of the BMS display (Figure 2). The scenario contained several phases with little action (e.g., infantry force movements, waiting for information from the UAV, etc.). To prevent boredom and waste of time, scenario-time was accelerated five fold. However, events that required real action (e.g., decision making) were run in real time. During SAGAT runs 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 and affiliation.

Situation awareness

SA is measured two or three times during each scenario using SAGAT (Endsley, 2000). Typical questions tapped all levels of SA including, perception, comprehension and projection. (See Appendix 1 for a detailed examples.)

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 provide verbal commentary, during the experiment. At the end of the experiment each SME underwent debriefing, based on a structured interview.

Experimental design and procedure

A between-subjects design was selected where each SME was 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. The overall length of each experiment was 4.5-5 hours, including breaks and debriefing.

Results

Six main types of results were analyzed: (a) 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) 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 (casualties, time loss, etc.). 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 groups the best answer was the least frequent. These results however, are not statistically 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 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 the control group did better. We were unable to offer a general interpretation of these results.

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 or two sources. The acquired information was actually 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 less information than the control group (Table 2). The difference is marginally significant (Pearson Chi-Square=5.239, df=2, p=0.073).

Table 2: 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 uncertainty was actually represented (199 cases) and those in which uncertainty was not represented (41 cases) . The analysis (Table 3) 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 - Pearson Chi-Square=7.743, df=2, p=0.03).

Table 3: 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	148	38	13	199
	percent	74.4%	19.1%	6.5%	100%
Not represented -	count	23	16	2	41
	percent	56.1%	39.0%	4.9%	100%
Total -	count	171	54	15	240
	percent	71.3%	22.5%	8.3%	100%

Effects of additional information on decision quality

Additional information improved decision quality. Table 4 presents the distribution of information request by decision quality. The results are marginally significant (Pearson Chi-Square = 7.737, df=4, p=0.1).

Table 4: The distribution 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

Individual differences

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

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. Mission completion time was 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.

Situation awareness

SAGAT questions (Endsley, 2000) addressed information in the close vicinity of the blue force and well as peripheral information that was considered relevant. selected the correct answer (out of three or four forced-choice 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.

Debriefing (SME comments)

At the end of each experiment 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 and the SAGAT questions a legitimate and relevant to the commander's mental model. Furthermore, several subjects indicated that such a simulation should be used to train

Gaps between reality and BMS representation

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…".

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). 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.

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. Some subjects suggested that uncertainty should be displayed as a layer that can be turned on and off upon request.

Discussion

The uncertainty manipulation

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. During the preparation of the experiment we were cautious 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 weakened the effects of uncertainty representation. It may therefore be concluded that uncertainty representation may be helpful under appropriate circumstances.

Response times

The uncertainty manipulation had no consistent effect on response times. This may indicate that the uncertainty manipulation did not add much workload. Alternatively, it may indicate that relatively little attention was 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 or two sources. Information received was useful in approximately 75 percent of the cases.

Information request frequency

The RAWFS model (Lipshitz and Strauss, 1997), states that under uncertainty, decision makers first try to reduce it by collecting more information. Our subjects made relatively little use of available information. Three factors may have suppressed expected behavior.

- Subjects tended to complete the mission as quickly as possible, refraining from additional information requests in order to save time.
- Some subjects randomly acquired non-useful information at an early stage and developed mistrust in the information.

- Even fairly experienced commanders may have failed to identify gaps between real world information and its BMS representations. In terms of RAWFS and based on subjects' debriefing, subjects employed alternative strategies. Instead of asking for more information. They used assumptions to fill in information gaps; surprisingly, uncertainty representation served as such "filler" (see next Section). Some subjects tended to suppress uncertainty and acted as it the picture was complete and certain.

Information requests in the experimental groups

The uncertainty group asked for less information than the control group. This result is counter intuitive because uncertainty representation was expected to foster awareness to uncertainty and promote requests for additional information. Apparently, uncertainty representation did strengthen awareness to BMS uncertainty but was also erroneously perceived as a substitute for additional information; allowing subjects to rely on Assumption Based Reasoning (Lipshitz and Strauss, 1997) rather than on actual information . Hence when uncertainty was actually represented it suppresses information requests but when missing it boosted the requests for 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; but when one or two sources of information were used, the best decision became the most frequent one.

Situation awareness

SAGAT questions (Endsley, 2000) yielded a fairly high rate of correct answers (52.2 percent). No significant differences were found between the experimental group and the control group. 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. In terms of Endsley's (1995) definition of SA - 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). In addition, even when SA was reasonably high, several SMEs lacked the ability to extract from it optimal decisions.

Individual differences

In general, there were large and significant individual differences in both decision quality and tendency to request additional information. Subjects' performance ranged from 13.3 percent selection of the best answer for the weakest subject to 60 percent for the strongest one (compared to 33.3 percent chance level). Senior commanders (battalion and deputy battalion commander) tended to perform better. 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; while the three weakest subjects took the best decision in only 13.3, 16.7 and 16.7 percent of the cases.

Zero-hour and mission completion

Subjects were asked to complete each scenario as close a possible to the zero-hour that was displayed at the bottom of the BMS monitor (Figure 2). The zero-hours were set such that they allowed time for information requests in approximately 50 percent of the decision points. In practice, subjects' control of the time was limited to decision points (all other stages of the scenario were paced by the computer). 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 (early) was 1348 seconds and the highest negative deviation (late) was 1133 seconds. Subjects who asked for little information tended to be consistently early, whereas, those who asked for much information tended to be late and those who were well-balanced finished relatively close to the zero hour. Interestingly, in the crashed helicopter team rescue mission most subjects tended to ignore the zero-hour and act as quickly as possible by refraining from additional information, resulting in an average of 683.9 seconds early. On the other hand, in a mission that involved friendly fire subjects tended to be much more cautious, asked for much more additional information and ended the mission 412.8 second late (average).

Debriefing

At the end of the four hour experiment, each subject was interviewed. In general, all subjects expressed positive appraisal of the experiment. Being highly busy officers most subjects found it difficult to spare five hours for the experiment. However, once they volunteered, they took the mission very seriously and took the time and patience to make comments and participate in the debriefing session. This positive appraisal confirms the experimental setup as a valid quantitative research tool in the C^3I area.

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 indicated that representation of uncertainty strengthens the awareness to the limitations of BMS information thereby fostering more cautious moves. Some subjects suggested that uncertainty should be displayed as a layer that can be turned on and off upon request.

A perspective on Sensemaking

Most decisions made during the present research were not optimal. Klein *et al.* (2007) defined Sensemaking as "exploiting information under conditions of uncertainty, complexity and time pressure for awareness, understanding, planning and decision making". Most failure causes defined by Klein *et al.* (2007) for individual performance (as compared to team performance) could be identified in the present results:

<u>Effect of Mental Models</u>: as revealed during debriefing, some subjects didn't have a clear notion in regard with the real value of BMS information and tended to perceive what they see as what really exists in the world; i.e., they employed a deficient mental models

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

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

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

Conclusions

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. Information must be comprehended and good decision making requires skill and experience.

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 were not clear-cut. We believe that with more training and increased understanding of BMS system capabilities (and limitations) the advantages of uncertainty information may increase. Such information (when available and reliable) should therefore, be an optional layer of information on the BMS.

Future research should focus on additional means for promoting Sensemaking with command and control systems. For example, Exploring the possible advantages of using 3D C^3I representations as compared to 2D representation; Using various perspectives of terrain representations (e.g., top down view versus panoramic view, flexible views controlled by the operator, etc.); and 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. It is hypothesized that the representation of real additional data (e.g., video) might yield significnaly more usage of additional information than found with the verbal messages in the present experiment.

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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.

Table 5: 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

Table 6: 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's 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 event 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.

Table 7: Scenario script – part 1

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 table 8	See Table 8	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

Second Part: 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 subject 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 priciples.

Appendix 2: The representation of uncertainty
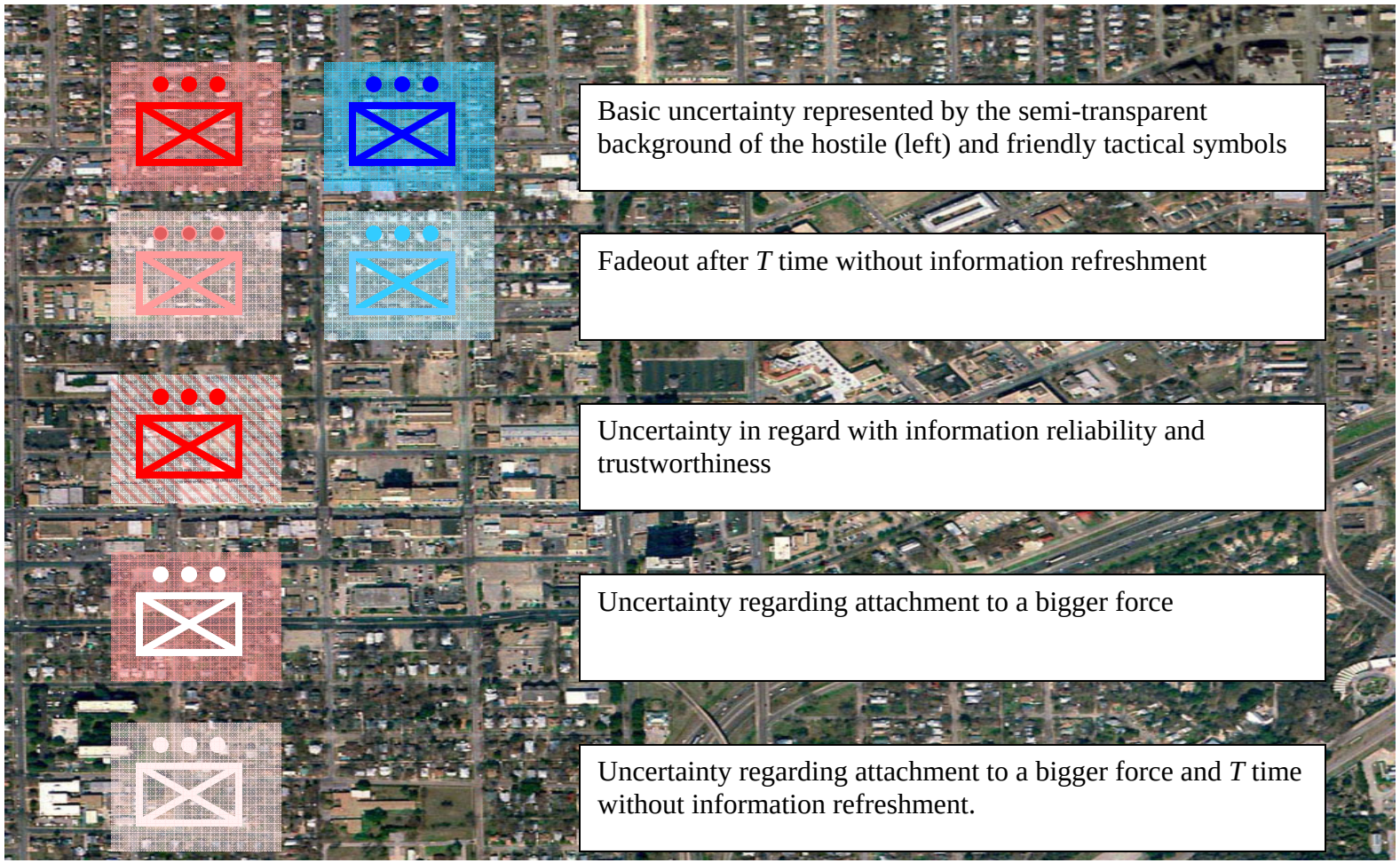
Figure 3: Uncertainty in general is represented by adding a semi-transparent background to the symbol. The examples below are all on the infantry tactical symbol but may appear in conjunction with any relevant tactical symbol.