

**14th International Command & Control Research and Technology Symposium
C2 and Agility**

**Theory and Evaluation of Battlefield Visualization in Context
Topic 1: C2 Concepts, Theory, and Policy**

Author

Celestine A. Ntuen

Army Center for Human-Centric Command & Control Decision Making

Center for Human-Machine Studies

419 McNair Hall

North Carolina A&T State University

Greensboro, NC 27411

Phone: 336-334-7780; Fax: 336-334-7729

Email: Ntuen@ncat.edu

Theory and Evaluation of Battlefield Visualization in Context

Abstract

This paper describes an on-going effort to develop operational visualization concepts and their technical implementations to support sensemaking skills based on the Army's Field Manual (FM) 3-0 doctrinal information on "Visualization, Detection, and Decide" requirements. A theory of visualization is presented from the stance that visualization is embedded and situated in human endeavors, and its cognitive activities. A visualization tool from Sensemaking Support System (S3) is used to evaluate this theory by using case vignettes from a Stability and Security Operation (SASO) domain to measure visualization impact variables. The evaluation metric was validated with eleven military personnel who are familiar with SASO situations. In addition to the inter-rater metrics and correlations analyses, a linear prediction equation that relates situation understanding as a function of evidential cues and Level 3 situation awareness is derived. The strength of the model is demonstrated by its high correlation factor ($R^2 = 83.7\%$) indicating its efficacy for use as a situation understanding prediction metric.

1.0. Introduction

We sometimes do what we think or intend, volitionally. We react to what we see, hear, touch, or feel. Reacting to the world around us is a part of a human endeavor that is mediated in part by what is generally known as visualization. Many military related doctrines have recognized visualization as a part of command and control (C2), predominantly because of visualization's ability to create agility in command decision making. The Department of Army's doctrinal handbook, Field Manual (FM) 5-0 (DoD, 2005) summarizes the commander's role in exercising C2 in ways that characterizes the human endeavors. These are: (1) Visualizing the environment; (2) Describing the commander's visualization to subordinates; (3) Directing actions to achieve results; and (4) Leading the command to accomplish the mission. Collectively, these endeavors are anchored on many cognitive processes that include, but are not limited to sense-making, situation awareness and situation understanding. However, sense-making provides the basis in which the human can gain an understanding of a situation.

Many conceptual discussions of future force battle command highlight the importance of visualization in enabling command and control. For instance, network enabled operations are founded on the premise that if the future force fully exploits both shared knowledge (collective visualization) and technical connectivity, then the resulting capabilities will dramatically increase mission effectiveness and efficiency. The Army's *Future Force Capstone Concept for 2015-2024 (DoD, 2007a)* outlines seven key operational ideas that characterize the capabilities of the future force; one of which is *Network-Enabled Battle Command*. The concept asserts that throughout future campaigns Network-Enabled Battle Command will facilitate the situational understanding needed for the self-synchronization and effective application of joint and Army combat capabilities in any form of operation.

With many doctrinal and academic research literatures reviewed, I argue that visualization and cognition are embodied and situated; externally, it enables situation awareness, and internally, it is controlled by the mind. It is the art and skill of creating

mental models of events or situations—therefore, it requires some level of expertise especially when dealing with problem solving or decision making; it is controlled, directed, and purposeful. Bringing various concepts on visualization together, I have identified at least eight ways in which visualization enables different human actions in situated contexts, especially in sense making of complex battlefield information. These are identifying system level constraints and boundaries, entity and event abstractions during model building, identifying decision spaces, state-space representation of problems of varying complexities, uncertainty handling, and information fusion through sense making, situation awareness, and situation understanding.

This paper discusses the applications of these factors to the development of a collaborative sense making support tool with visualization applets used to enable human actions in battlefield domains. Visualization applications within the domain of stability and security operations (SASO) that provide real-time dynamic situation awareness are demonstrated. The implications of on-going findings to human factors and cognitive engineering of battlefield visualization information are discussed.

2. Theory of Information Visualization

Visualization has been noted by psychologists and philosophers (e.g., Searle, 1983) to occur internally in the mind and externally mediated by ecological information (Gibson, 1978). The mind itself carries abstract information such as thought, ideas, perceptions, feelings, and memories. The mind is responsible for shaping of meaningful spaces for situation understanding through logical assignments of concepts and their saliencies. In the process of visualization, the mind expresses this in terms of imagination, precepts, and creativity through the ability and capacity to conceive ideas and concepts that precede cognition. Figure 1 captures this anecdotal explanation.

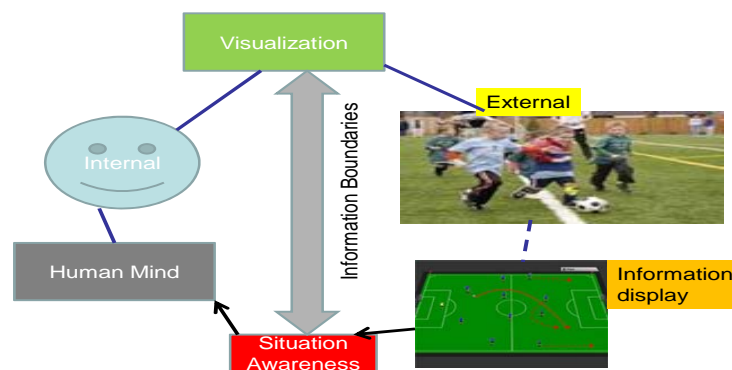


Figure 1. A simple theoretical view of visualization

As seen in Figure 1 above, visualization is controlled by both internal and external events. Internal events are those controlled by the mind and other neurological information processing elements. The reader is referred to Broad (1937) for more discussions on mind, consciousness, and visualization. The conscious mind is responsible for self awareness. Coupled with the individual experiences, volitions and intents (Ntuen

and Woodrow, 2005) are created. Selective information representation, recall, and presentation occur effortlessly in the mind in a manner that internal visualization is effortless and automatically controlled.

On the other hand, external events are ecologically mediated and provide information in the form of symbols, signs, and signals which are responsible for building the mental codes of the universe of interest. The external events which are graphically portrayed and rendered as displays, allow us to gain a nominal level of situation awareness known by Endsley (1995) as Level I situation awareness (SA) because of the information processing at the sensory-perceptual stage. The mapping of visualization to the elements of SA is constrained by barriers within the information boundaries. For instance, during the transitions from Level I SA to Level II SA, the comprehension stage is made possible by special filters which are contributed by neural-cognitive processes and the information changes from outside. The outside information stimuli mediate most of the cognitive activities that occur internally. Examples include, pattern mapping and recognition, being able to guess or estimate quantity in a graph, predicting a system state, and so on.

In the battlefield operational environment, information is generated, collected, and distributed to all processing agencies. These activities are externally controlled. However, the representations of this information are implicit internal activities with specific epistemic and representational requirements. Information representation in any form or modality provides a basis for human reasoning aimed at improving the operational effectiveness of decision processes. In this case, the human reasoning bottom-up with known data (backward-chaining), seeks to generalize from specific observations. Retrospectively, it is an attempt to correlate new information with existing ones in the long-term memory.

Information from the operational environment also provides the human operators with cues responsible for alerting the operator with important awareness which could not have been possible otherwise. The relationships between the internal and external events that control visualization process can best be understood by understanding the information boundaries created by these neuro-cognitive events. The study in this area is scarce.

Building from the above explanations, visualization is constructed from many cognitive stances. Card, et al., (1998) define visualization as a form of data representation that enables cognitive processes such as decision making. Koffka (1935) emphasizes the use of visualization as a symbolic communication tool—"as a skillful use of image". The Army's Field Manual (FM) 3-0 (DoD, 2008) views visualization as a mental process towards situation understanding such as "determining a desired end state, and envisioning how to move from one state of a system to another". Since the commanders and staffs use visualization to look for knowledge in order to build the required actionable intelligence, our discourse is focused on knowledge visualization. Knowledge visualization is a visual explication of conceptual knowledge through conscious SA for the sole purpose of exploiting the visual parameters, encoding salient features graphically, providing a useful process, and producing a useful knowledge for understanding a problem situation.

Card, et al., (1998) also observe that information visualization is useful to the extent that it increases our ability to perform many cognitive activities; and, "the real power comes from devising external aids that enhance cognitive abilities; for the sole

purpose of knowledge discovery, decision making, and explanation.” Visualization tools are therefore useful in supporting direct cognition of information in context of a domain environment. It is useful for gaining insights into external cognitions in context. As noted by Eppler and Burkhard (2004), knowledge visualization allows visual representations to improve the creation and transfer of knowledge between people by sharing what they know and what they need to know through perception making and sharing. Because of the interaction between the external and the human (internal) minds, visualization can allow people to express and share their beliefs, values, experiences, and individual intentions. The sharing of the commander’s intent with battle staffs using graphical displays or overlaid maps is just an aspect of the power of visualization in situation cognition. On this note, visualization can be constructed as a social interaction model in which a group cultural cognition can emerge. As a community, the battle staff can use visualization aids to create and reproduce knowledge through social relationships and interactions defined by common standard operating pictures, doctrines, and tactics, techniques, and procedures (TTPs). However, notes Novak and Wurst (2004), “in order to make sense out of information and construct knowledge, one needs to contextualize it within one’s own existing knowledge and thought world.”

While visualization tools allow decision makers to see cues and patterns of information in space, they also influence the use of two important types of cognitions. These are reflexive and reflective, respectively. Reflexive cognition generates an automatic response (Shriffin and Schneider, 1977) to decision making because of an effortless mapping of visualized information cues or patterns to mental image or image carried in the human mind. This is useful in a non-deliberate decision making where situations change rapidly with some dimensions of chaos and complexity. On the other hand, reflective cognition is the term used in cognitive psychology (Neisser, 1967) to describe conscious and thoughtful reaction to stimuli. Reflective cognition is useful for generating prospective plans which force the individual to adapt a familiar procedure to a new situation. Since the familiar procedure may not match the incumbent situation, a trial and error approach is enacted. Reflective cognition, therefore, is the result of interaction: our ability to learn new things come from encounters with the unexpected (that which lies outside our experience, that which is not part of our experiential cognition) that turn our path, leading to new knowledge.

Thus, visualization may not only constrain the way we can interact in the world, but can help us to determine the way the world appears to us. In terms of human tacit knowledge, visualization may not necessarily use data—it depends on how we form images and mental models of what we know through experience. When computer and other technological related support systems are used to render or display information, visualization becomes an aspect of what Polyani (1966) refers to as focal knowledge. Both tacit and focal knowledge are the major enablers of sense-making and sense making processes.

3. Battlefield Visualization

3.1 Doctrinal Views of Visualization

According to the Army's FM 3-0 (DoD, 2008), "Commander's visualization is the mental process of achieving a clear understanding of the force's current state with relation to the enemy and environment." Visualization represents an aspect of embodied cognition because the cognitive processes are mitigated with the environment of information displays. These displays are contextually represented and rendered to provide cognitive affordance between the human and the system. As an embodied artifact, visualization can serve to amplify (e.g., elaborate and strengthen) or attenuate (reduce) our cognitive ability. The general doctrinal structure of battlefield visualization from the human dimension is shown in Figure 2 below.

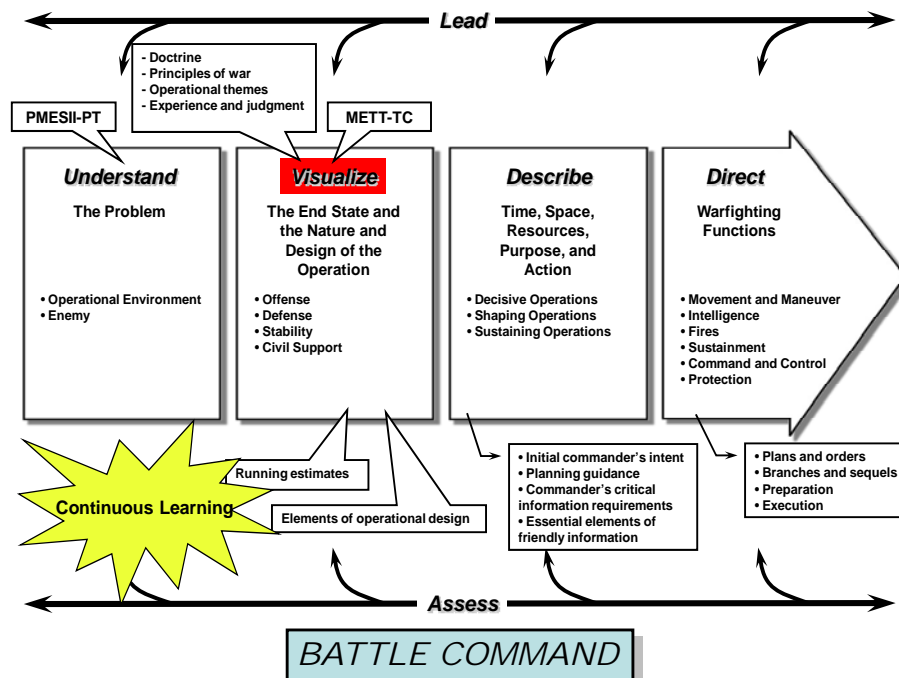


Figure 2. From FM 3-0, Figure 5-1: Visualize, Describe, Direct; pp. 5-4.

The commander's visualization is the mental process of achieving a clear understanding of the force's current state with relation to the enemy and environment. This is enabled by good SA, situation understanding, critical thinking and knowledge discovery rules and algorithms. In general, visualization helps in pattern recognition tasks through interactive graphical presentation of information. Thus, visualization may not only constrain the way we can interact with objects in the world, but can help us to determine the way the world appears to us. In terms of human tacit knowledge, visualization may not necessarily use data, and thus can be used represent how we form concepts around our mental models.

3.2 . Battlefield Visualization Evaluation in Context

Many military related doctrines have recognized visualization as a part of C2, predominantly because of visualization's ability to create agility in command decision making. Lieutenant General William S. Wallace (2005) notes that in the Battle Command concept, commanders use a personal decision-making process that incorporates visualizing the operation, describing the operation in terms of intent and guidance, and then directing actions within that intent. FM 5-0 (DoD, 2005) define battle command to include visualization as a tool to predict the current and future states of the battlefield; and the Army Transformation Road Map (DoD, 2004) elucidates the benefit of visualization in terms of "seeing and knowing" the friendly and enemy forces and then deciding how to get from one to the other at least cost.

Visualization models in the battlefield should allow the commanders and battle staffs to frame better hypotheses about the information in the environment, and reason bottom-up or top-down (deduction or induction) or laterally (abduction) in order to gain an understanding of the context of interest. The representative visualization process often used include link maps, conceptual maps, symbols, decision trees, semantic diagrams, and videos, animations, and data plots. The military doctrines emphasize that commanders should be able to visualize a dynamic battlefield with some accuracy and use of the results to their decision making advantage. A commander who develops this difficult skill can reason proactively like no other. "Seeing the battlefield" allows the commander to anticipate and adapt quickly to changing situations.

The relationship between sense-making and visualization is clearly stated in the Army's FM 3-0 (2008) operations handbook which notes that visualization is a purposeful activity since it enables people to detect the elements of a situation before making any decision. That is, one engages in battle space visualization for the specific purpose of identifying specific actions that can be taken to influence the present situation and move it toward an intended objective or end state:

--Commanders, assisted by the staff, visualize the operation, describe it in terms of intent and guidance, and direct the actions of subordinates within their intent... The volume of available information challenges all leaders. They assimilate enormous amounts of information as they visualize the operation, describe their intent, and direct their subordinates' actions. Visualizing the operation is continuous. It requires commanders to understand the current situation, broadly define the future situation, assess the difference between the two, and envision major actions that link them.

Visualization is not limited to any particular person in the command hierarchy since even the field soldier must use visualization skill to deal with the "information out there." Therefore, battlefield information visualization is the core mental process that supports decision-making and by which the art of command and the science of control are realized. For the battalion commander for instance, it is the process of achieving a clear understanding of the battalion's current state with relation to the enemy. These include the terrain, mental representation of the objectives such as avenues of approach diagrams, and determining the sequence of activities that moves the battalion from its current state to the end state. The commander's visualization is the assessment tool throughout the operation.

At the C2 level, the commander identifies the dynamics of opposing forces by using a visualization process. This includes evaluating possible enemy reactions and

friendly counteractions. This evaluation may lead to the identification of possible critical decision points throughout the operation. Visualization tools supporting the commander's cognitive tasks should have information displayed in a manner that best supports the acquisition, exchange, and use of information. Examples include the use of realistic semiotic representations to portray terrain information and information fusion of uncertain and disparate information. Three-dimensional representation of information (i.e., terrain, airspace management, or weapons engagement envelopes) should be realistically portrayed (Barnes, 2003). Information displays must support on-the-move operations. Decision oriented graphics symbology should be displayed clearly. Operators must have the ability to change graphics interactively. Having a relevant common picture will enable the commander to operate within the enemy's decision cycle by synchronizing forces and dictating the operational tempo. This relevant common picture must be comprised of timely, accurate, and relevant friendly and enemy situational and status information laid over a common, near-real-time representation of the area of operation (including elevation and natural and man-made features). Having real-time SA across the battlefield will enable the commander to intuitively picture the friendly and enemy situation and reduce battlefield uncertainty by displaying friendly and known enemy force location and status. The relevant common picture must be scalable to the appropriate levels of command, tailored by functions, and based on the user determined parameters.

4. Performance Evaluation of a Battlefield Visualization Tool

4.1. Visualization Performance Factors

Battlefield visualization gives a constant reference to use of tacit knowledge that includes: (a) a hybrid of covert visualization and sense-making such as manifested in the commander's intent and guidance; and, (b) situation awareness which is guided by both external and semiotic knowledge consisting primarily of ecological sense-making and focal knowledge: an example is the description of the commander's priority information requirement developed by the battle staff. Ntuen (2009) has recognized three factors that govern these assumptions: (1) Visualization cannot be separated from the context in which the objects of displays and the grounding knowledge for representation are derived. (2) Visualization that occurs in the mind are equally, if not more important to the physical phenomenon expressed by and adopted by situation awareness community. And, (3) the organization of information in a display and visualization system can influence the human information access as well as delimiting performance. It is surmised that any visualization evaluation metric should address at minimum, the information at each of the three factors above.

Past efforts on visualization evaluation have focused on SA. And most of the methods have been subjective using self-rating techniques. Self-rating techniques seek subjective evidence of SA by eliciting the individuals' own self-perceptions. Some examples include, Situational Awareness Behaviorally Anchored Rating Scale (SABARS), a technique used by expert observers to rate individuals on a number of observable behaviors related to SA processes (Strater, et al., 2001). This approach is an extension of such tools as the Participant Situation Awareness Questionnaire (PSAQ)

used by Matthews, et al., (2000), the Situational Awareness Rating Tool (SART) of Taylor (1990), and the Crew Awareness Rating Scale (CARS) described by McGuinness and Foy (2000). Probe techniques or query techniques seek direct evidence of the content of individuals' SA. In this method, the metrics attempt to elicit a set of information from the individual on his or her perception and understanding of the situation, and then comparing this against the real thing, the ground truth.

For experimental evaluation, Clauser and Fox (2005) have identified a framework (Figure 3) that contains the knowledge facets relevance to the above assumptions, and which also attempts to capture both the tacit knowledge (sense-making factors) and the extrinsic visualization attributes. The information in the right-hand part of Figure 3 is added to illustrate the examples of cognition-visualization embodiments. The performance variables are derived from this representation and measured in the evaluation are shown in Exhibit 1.

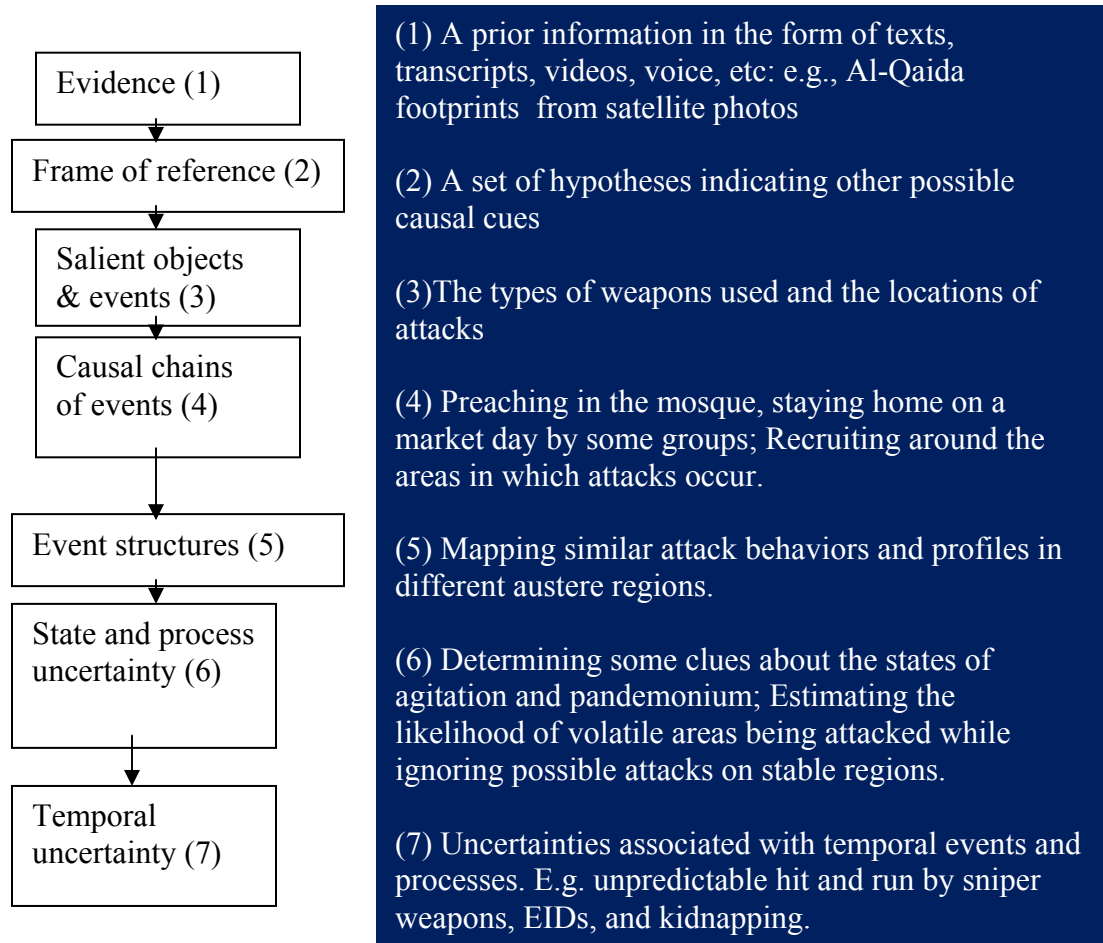


Figure 3. The sense-making/ Information visualization metaphor framework

4.2 Subjects

Eleven experienced military officers participated in the study voluntarily. Four of the participants were picked through advertisement and personal meetings with the Army Reserve Officer Training Corps (ROTC) at North Carolina Agricultural and Technical State University (NCA&T). Five participants were from the civilian (retired) military

population working at NCA&T, and two officers from reserved army component in Greensboro. All participants passed the requirements of: (1) a rank of Lieutenant and above; (2) experience commanding a troop at a platoon level and above; and, (3) have combat experience in modern conflicts such as in Kosovo, Gulf war, Iraq, or Afghanistan. All participants had a combined military experience of 163 man years with a standard deviation of 11.73 years.

On a scale of 1 to 7 (1 = absolutely not useful and 7 = absolutely very useful) give rating to the following items based on the situation visualization and display and the tasks you are asked to perform:

X1: **Situation Understanding:** The ability to translate situation information into actionable knowledge for decision making.

X2: **Evidence:** The amount of evidential cues and clues provided and gained during the visualization process.

X3: **Frame of Reference:** The ease to which the display cues support and enable the development of plausible hypotheses related to the event causes.

X4: **Information Foraging:** The ease to which the visualization tool helps in information seeking and extracting for sensemaking.

X5: **Causal Chaining:** The ease to which the visualization tool helps to trace the causal linkages between the events and effects.

X6: **Team sensemaking:** The ease to which the visualization tool allows the team to collaborate.

X7: **Level-3 SA:** The ease to which the visualization tool allows the user to predict the future states of the situation and the effects.

X8: **Belief Revision:** The extent to which the visualization tool helps the sensemaker to change opinion and/or revise belief because of new information.

Exhibit 1. Performance variables used for visualization tool evaluation.

4.3 Apparatus

The apparatus consisted of Sensemaking Support System (S3) software (Ntuen and Gwan-Myung, 2008), a personal computer, and 18" TV monitor. The S3 software developed for use as a team or an individual level sensemaking. It is useful for sensemaking at the individual and team levels, respectively. This collaborative knowledge sharing is crucial to the battle staffs that must collectively connect their experiences and share their perspectives on how the battlefield information is related to the mission and the commander's intent.

The current features in S3 allows up to three users to conduct sensemaking based on selected problem scenarios. Each user logs into S3 with a protected password and first completes a team profile survey (TPS). The left side of Figure 4 allows at least one user to log into the system. The right side shows an example event triggered by a rocket propelled grenade. The S3 display has different levels of information to be queried by the user during a sensemaking session. The user can use a white board to draw avenues of approach or potential enemy locations. S3 also allows the user to search for information using text browsing on the web. Other decision information can be displayed through use of statistical analysis tools on Excel spreadsheet.

For the present study, a case on SASO from Battle Command Battle Laboratory of Fort Leavenworth provides the vignette that drives the SASO simulation (SASOSIM) support system. SASOSIM is a hybrid of S3 and constructed simulation models of

SASO behaviors over time. SASO has components for simulating both the DIME and PMSEII mapping strategies.¹

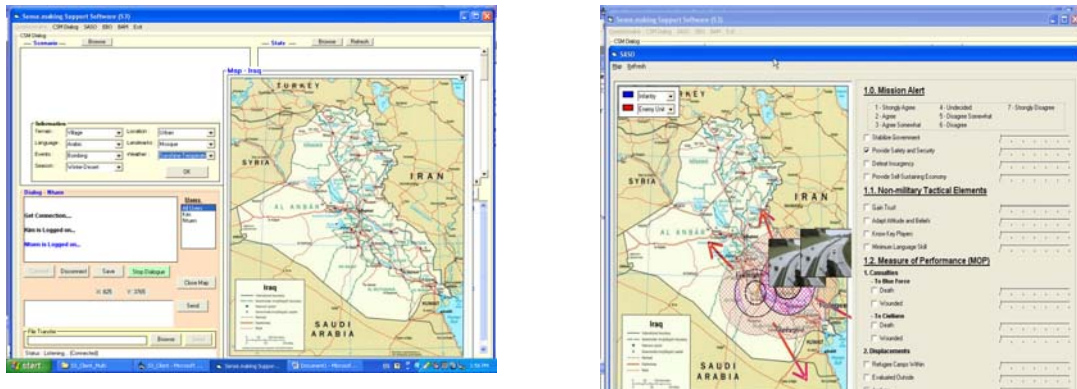


Figure 4. Sample S3 screen captures.

4.4 Procedure

Each officer participated in a team of two “battle staffs” because of the current limitation of S3 in a laboratory setting. Ideally, there were 55 team-pairs. However, because of time schedules and availability of the participants, 35 pair-trials were completed, but the post experiment questionnaires were administered to the individuals separately, yielding 11 observations per performance variable shown in Exhibit 1. The study took 9 days of one hour per session per team. The participants was told to use the S3 software to conduct sensemaking exercises based on a simulated terrorist attack in a city in Iraq. The sensemaking exercises use query methods to assess and collect information on each event. For examples, when an event occurs, the team will assess the situation to answer such questions as: (a) Who is responsible? (b) When did it happen? (c) Who are responsible for the attack? (d) What are the effects (economic, migration, etc.)? (e) What are the likely reasons for the attack? (f) What other targets are next possible candidates for attack? Note that these sensemaking queries contain the information elements in Figure 3. For instance, question (a) is related to assumptions or hypotheses formulation through framing.

Note that this paper does not report on the outcomes of the sensemaking process but on evaluating the contribution of the S3 visualization to the sensemaking process. At the end of a scenario, the participants were asked to subjectively rate the effectiveness of S3 as a visualization tool against the variables given in Exhibit 1, with mean rating statistics in Table 1 and discussed below.

4.5 Data Analysis

Three types of analyses were collected, the mean, correlation, and regression coefficients. The first is the mean and standard deviations, and the inter-rater ratings scores are shown in Table 1 with a plot in Figure 5. The right side of Table 1 has the inter-rater agreement values using the model developed by Williamson and Manatunga (1997). Except for X5, the causal chaining variable, all visualization impact variables show some agreement with corrected Fisher test per Williamson and Manatunga (1997).

¹ [DIME is an acronym for Diplomatic, Informational, Military, and Economics and PMSEII stands for Political, Military, Economic, Social, Information, and Infrastructure]

That is, there was some agreement on these variables as measures of visualization impact on sensemaking.

Table 1. Mean Rating Statistics on Visualization Impact Variables

Criterion	Mean	Std	Inter-rater coefficient
X1	5.16	1.32	0.422
X2	3.83	1.51	0.367
X3	3.6	1.33	0.417
X4	5.57	1.09	0.503
X5	3.67	1.62	0.322^a
X6	4.28	1.28	0.435
X7	5.93	1.14	0.485
X8	5.47	1.05	0.517

^anot statistically significant at $p \leq 0.01$.

On the mean scores, when a two-pair comparison test with Turkey statistics was performed using the overall mean score of 4.33 across all variables, variables X3 and X5 were significant at $p \leq 0.1$ while others were significantly different at $p \leq 0.05$.

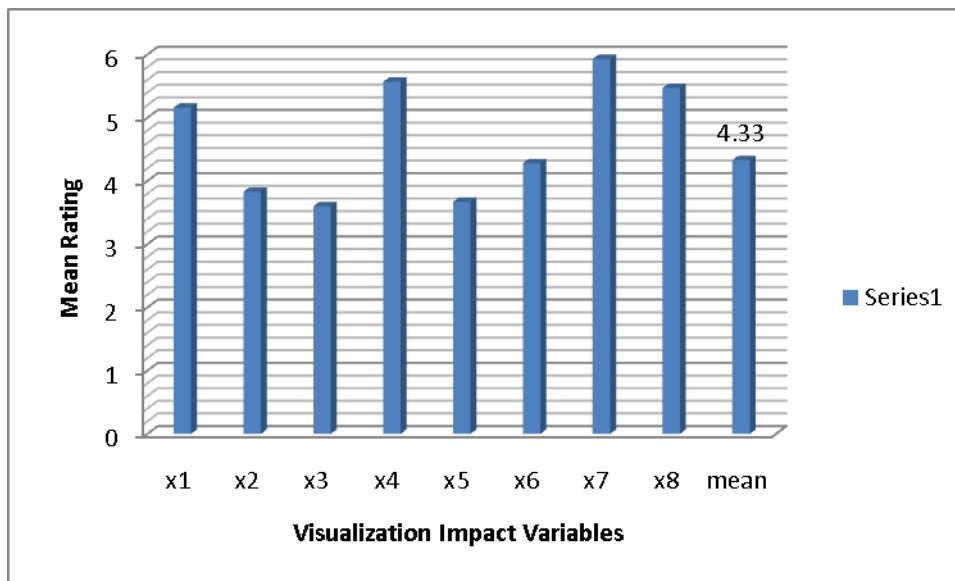


Figure 5. Mean scores by visualization impact variables.

In general, the following variables received above the population mean score: Level 3 SA (X7) was prominent, followed by information foraging (X4), support in belief revision (X8), and situation understanding (X1). The variables X6 (team sensemaking) and X2 (seeking evidence) did not show any statistical differences in mean scores. The Pearson correlation analysis was conducted with statistical analysis system (SAS)

software as outlined by Marasinghe and Kennedy (2005). The result of the correlation analysis is shown in Table 2.

As shown in Table 2, there is no statistical relationship between how people frame a problem (X3) and: (i) how they seek information (X4); (ii) the causal chain reasoning process used (X5); and, (iii) team sensemaking (X6). Similarly, there is no evidence of

Table 2. Pearson Correlation Coefficients for Visualization Impact Variables

	X1	X2	X3	X4	X5	X6	X7	X8
X1								
X2	0.48							
X3	0.61	0.717						
X4	0.633	-0.416	??					
X5	0.688	0.34	??	0.816				
X6	0.739	0.672	-0.331	-0.643	??			
X7	0.802	0.445	??	0.381	0.428	0.726		
X8	-0.575	0.716	-0.359	0.353	0.315	-0.527	??	

?? indicates non significant at $p \leq 0.05$.

of relationship between the individual causal chain reasoning (X5) and team sensemaking; and, between team sensemaking and how individuals revise beliefs when given new information (X8).

There were some striking negative correlations that need some explanation. These are: (a) the correlation value of -0.416 between evidence and information foraging indicates that a sensemaker who has an evidence about a situation may not be seeking for more information; i.e., as more evidence is known, the less the opportunity to seek more information; (b) the correlation value of -0.575 between situation understanding and belief revision indicates that as the individual achieves a better situation understanding, the less likely that he or she will change an already hold opinion. This is a typical effect of availability bias which asserts that people use the available information in the memory to estimate what is more likely in a situation(Kahneman,et al., 1999); (c) a correlation value of -0.331 between problem framing (X3) and teams sensemaking (X6) indicates that an individual has the tendency to frame a hypothesis different from the team view; (d) a correlation value of -0.359 between problem framing (X3) and belief revision indicates that individuals may not likely change their beliefs once they are fixed on a set of hypotheses. This is typical of anchoring bias (Evans, 1989) which asserts that people have the tendency to rely too heavily on a past reference retrospectively during sensemaking; it takes special methods to disrupt the stereotypical fixation; (e) a correlation value of -0.643 between information foraging (X4) and team sensemaking (X6) indicates the possibility that individual may not likely seek new information once the team have some consensus information for a problem situation; and (f) a correlation values of -0.527 between team sensemaking (X6) and belief revision shows the likelihood that team members may not change their beliefs once a consensus is reached.

Note that all positive correlations indicate some increasing relationship between the variables. For example, a correlation coefficient of 0.726 between team sensemaking

(X6) and Level 3 SA (X7) confirms the strength and necessity for supporting team sensemaking with common visualization support (Endlsley, 2000).

The last analysis was to develop a prediction equation for situation understanding (X1) as a function of evidential cues (X2) produced by the visualization domain and the Level 3 SA (X7). Here, situation understanding (SU) is considered a linear addition of SA and cue (evidence effects): $SU = SA + \text{Cue}$; in the current representation, $X1 = X7 + X2$.

A linear regression of the best fit gives the model:

$$X1 = 2.3 + 0.42 X2 + 0.16X7 (R^2 = 0.837; p = 0.0003).$$

The above relationship is true for the rating range $1 \leq X \leq 7$.

5. Summary and Conclusion

This paper has described an on-going effort to develop operational visualization concepts and their technical implementations to support sensemaking skills based on the Army's FM 3-0 information on "Visualization, Detection, and Decide" requirements. First, visualization is our attempt to allow the sensemakers to "see the same thing" in place and time so as to gain real-time situation awareness. Through visualization, the team members can share their mental models, present their perspectives either textually or graphically.

A theory of visualization was presented from the stance that visualization is embedded and situated in human endeavors. The S3 visualization tool was used to evaluate this theory by using case vignettes from a SASO domain to measure visualization impact variables (VIVs). A VIV is a variable related to visualization and the sensemaking process and serves as a moderator to amplify good sensemaking or impede the sensemaking process. The evaluation metric was validated with eleven military personnel who are familiar with SASO situations. For simplicity, one type of event was evaluated. However, the S3 visualization tool can allow for experiment with many types of events at different levels of complexities (Ntuen, 2006b). In addition to the inter-rater metrics and correlations between the VIVs, a linear prediction equation for a situation understanding was derived as a function of evidential cues and Level 3 SA provided by the visualization tool. The power of the model was $R^2 = 83.7\%$ indicating its efficacy for use as situation understanding prediction metric.

ACKNOWLEDGMENT:

This project is supported by Army Research Office (ARO) Grant # W911NF-04-2-0052 under Battle Center of Excellence initiative. Dr. Celestine Ntuen is the project Principle Investigator. The opinions presented in this report are not those of ARO and are solely those of the authors.

References

- Barnes, M.J. (2003). *The Human Dimension of Battlespace Visualization: Research and Design Issues*. Army Research Laboratory: Aberdeen Proving Ground, Maryland, ATL-TR-2885.
- Broad, C.D. 1937: *The Mind and its Place in Nature*, London, Routledge and Kegan Paul.
- Card, S.K., Mackinlay, J.D., & Schneiderman, B. (1999). *Readings in Information*

- Visualization; Using Vision to Think. Los Altos, CA: Morgan Kaufmann.
- Clausner, T.C. (2005). A framework and toolkit for visualizing tacit knowledge. HRL Laboratories Report.
- Chen, C. and Paul, R.J. (2001). Visualization of a knowledge domain's intellectual structure. *IEEE Computer*, 34: 65-71.
- DoD (2008). U.S. Department of Army FM 3-0: Operations.
- DoD (2007a). The United States Army Functional Concept for Battle Command (2015-2024). TRADOC pamphlet 525-3-3, Version 1.0, 30 April.
- DoD (2007b). U.S. Department of Army FM 1 1-0.01: SI Operations.
- DoD (2005). U.S. Department of Army FM 5-0: Army Planning and Order Production.
- DoD (2004). U.S. Department of Army: 2004 Army Transformation Roadmap.
- DoD (1997). U.S. Department of Army FM 100-8: The Army in Multinational Operations.
- Endsley, M.R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors*, 37(1), 65-84.
- Endsley, M.R. (2000). Direct measurement of situation awareness: Validity and use of SAGAT. In: M.R. Endsley & D.J. Garland (Eds.), *Situation Awareness Analysis and Measurement*. Mahwah, New Jersey: LEA.
- Eppler, M., and Burkhard, R. (2004). Knowledge visualization: Towards a new discipline and its fields of applications, referenced in Novak and Wurst (2004).
- Evans, J. St. B.T. (1989). *Bias in Human Reasoning: Causes and Consequences*. Hilldale, NJ: Lawrence Erlbaum Associates.
- Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton-Mifflin.
- Kahneman, D., Slovic, P., and Tversky, A. (1999). *Judgment under Uncertainty: Heuristics and Biases*. Cambridge, UK: Cambridge University Press.
- Koffka, K. (1935). Principles of gestalt psychology. *Psychological Bulletin*, 19, 531-585.
- Marasinghe, M.G. and Kennedy, W.J. (2005). *SAS for Data Analysis*. New York: Springer.
- Mathews, M.D., Pleban, R.J., Endsley, M.R., and Strater, L.D. (2000). Measures of infantry situation awareness in a virtual MOUT environment. In: *Proceedings of the 1st Human Performance, Situation Awareness and Automation Conference*, Savannah, Georgia, 15-19 Oct 2000. SA Technologies, Inc.
- McGuinness, B. and Foy, L. (2000). A subjective measure of SA: The Crew Awareness Rating Scale (CARS). In: *Proceedings of the 1st Human Performance, Situation Awareness and Automation Conference*, Savannah, Georgia, 15-19 Oct 2000. SA Technologies, Inc.
- Neisser, U. (1967). *Cognitive Psychology*. Appleton-Century-Crofts: New York.
- Novak, J. and Wurst, M. (2004). Collaborative knowledge visualization for cross-community learning.
- Ntuen, C.A. (2009). Sense-making and visualization for situation cognition. *Naturalistic Decision Making and Computers Conference*, London, (To appear).
- Ntuen, C.A., and Gwang-Myung, K. (2008). A sensemaking visualization tool with military doctrinal elements. *Proceedings for 13th International Command & Control Research and Technology Symposium*. Seattle, WA.
- Ntuen, C. A. (2006a). Cognitive Constructs and the Sensemaking Process. *Proceedings for 11th International Command & Control Research and Technology Symposium*. San Diego, CA.
- Ntuen, C.A. (2006b). The knowledge structure of the commander in asymmetric battlefield: The six sights and sensemaking process. *Proc. of 2006 CCRTS Conference*. San

- Diego, CA (June).
- Ntuen, C.A. and Woodrow, W.W. (2005). Self-awareness meets situation awareness: Making tacit knowledge explicit through situation display. *In Proceedings of the 2005 Human System Integration Conference*, Washington, D.C.: Navy).
- Polyani, M. (1966). *The Tacit Dimension*. Doubleday.
- Searle, J. R. (1983). *Intentionality*. Cambridge: Cambridge University Press.
- Shadrick, S.B., Lussier, J.W., and Fultz, C. (2007). Accelerating the development of adaptive performance: Validating the Think Like a Commander training. Arlington, VA: U.S. Army Research Institute for Behavioral and Social Sciences.
- Shriffin, R.M. and Scheider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, 84, 127-190.
- Taylor, R.M. (1990) Situation Awareness Rating Technique (SART): the development of a tool for aircrew systems design. Paper 3 in: *Situational Awareness in Aerospace Operations*, AGARD-CP-478. Neuilly-sur-Seine, France: NATO-AGARD. pp. 3/1-3/17.
- Wallace, W. S. (2005). Network-enabled battle command. *Military Review*, May-June, 2-5.
- Weick, K.E. (1995). *Sensemaking in Organizations*. Thousand Oaks, CA: Sage Publications.
- Williamson, J.M., and Manatunga, A. K. (1997). Assessing inter-rater agreement from dependent data. *Biometrics*, 53(2), 707-714.