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Identifying and Quantifying Critical Information Streams for Tactical Combat Decision Modeling

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Abstract: It is often asserted that more information on the battlefield leads to greater situational awareness (SA) which, in turn, translates to enhanced mission performance and outcomes. However, the volume of available information on the modern networked battlefield is extensive and growing, which induces risk of indecision due to cognitive overload. The potential overload highlights the need to streamline the flow of information to those critical streams that provide the most value to a tactical leader's decision process at particular points in time. The purpose of this study is to identify critical information streams required by tactical leaders within the various phases of a dismounted search and attack/react to contact scenario. Domain Mapping Matrix methodology (DMM) is utilized to quantify the value of various information streams relative to the sub-phases within the scenario using a constructed nominal scale. The significance of the highlighted interactions is validated through the use of statistical analysis, with combat veterans serving as test cases. The findings of this study will facilitate the development of decision models that will eventually enable more accurate and realistic simulation of the leader's decision processes that increased SA purportedly enhances.

Keywords: Situational Awareness, Domain Mapping Matrix, Human Decision Modeling

1. Introduction

Quick access to information and complete situational awareness (SA) can be decisive in combat. This study examines the various components of situational awareness to enable more efficient research and the acquisition of future SA-enabling military technologies. Currently, a gap exists between the information provided to soldiers on the battlefield and whether that information correlates to better overall performance. An enhanced degree of SA is presumed to enhance operational decision - making processes and, by extension, the operational results themselves. However, accurate measurement of these benefits requires a greater understanding of the decision-making processes themselves and how more/less and better/worse information affects them.

To bridge this gap, the most critical pieces of information must be identified and then evaluated to determine relative value at key decision points in a tactical situation. We used the inputs of nearly 70 officers and non-commissioned officers with combat experience combined with Domain Mapping Matrix (DMM) methodology to establish the criticality of information streams at each phase of a dismounted search and attack scenario. These quantified streams form the basis of inputs into a multi-attribute utility function to model the tactical decision-making processes at the team and squad levels. The overarching goal of this work is to provide a usable addition to the existing operational architecture for a search and attack scenario which visually depicts the influence of the critical information streams. This addition will allow for combat simulation modelers to fill the recognized gap and measure the operational benefit of enhanced situational awareness.

1.1 Literature Review

Situational awareness is defined as "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" (Endsley, 1995). As shown in Figure 1, SA occurs in three unique levels: perception, comprehension, and projection. These levels interact with certain decisions, which are also shaped by various other factors in the decision-maker's environment. A common premise is that enhanced SA improves decision making, which is a “function of an individual’s information-processing mechanisms, influenced by innate abilities, experience, and training” (Endsley, 1995).

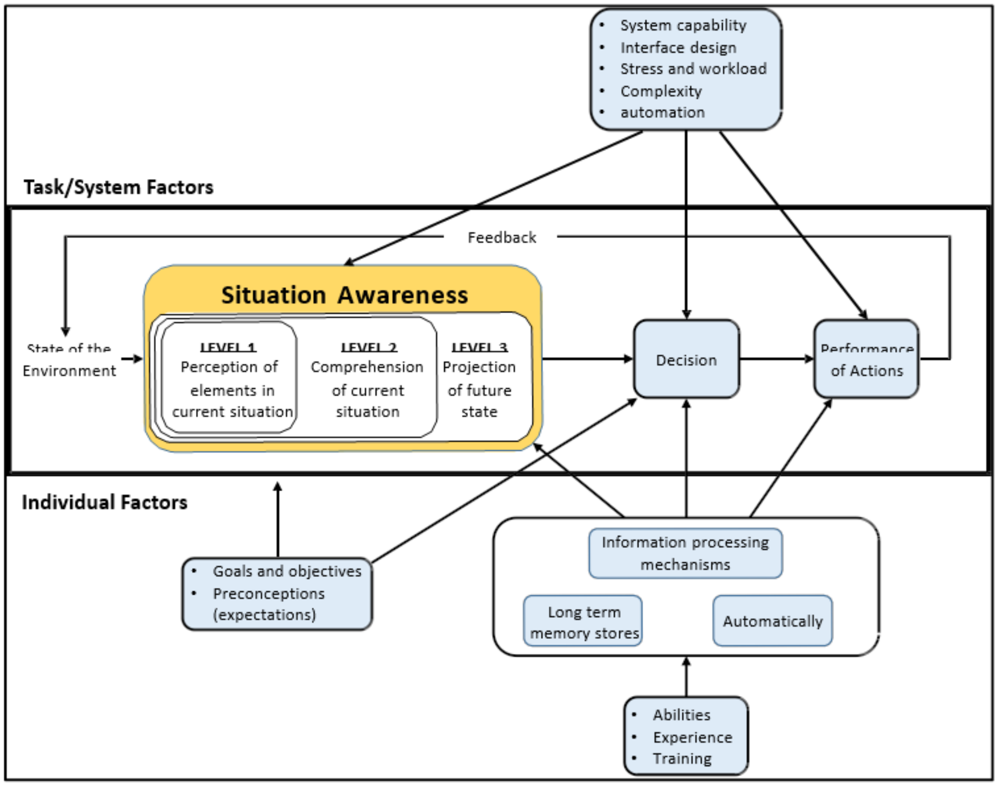


Figure 1. Model of Situational Awareness in Dynamic Decision Making (Endsley, 1995)

Anticipating uncertainty in the future operating environment, and an enhanced role of the squad therein, General Martin Dempsey established a requirement to ensure that the rifle squad would have the ability to achieve what he termed “overmatch” (Mundweil, 2013). The Maneuver Center of Excellence (MCoE) defines overmatch as:

> The ability to successfully execute critical tasks against projected threat forces in all operational environments concluding with decisive operations that drive the adversary to culmination and achieving the operational objectives while retaining the capability to continue with subsequent missions.

Mundweil (2013) analyzes overmatch and in what capacity the US Army employs overmatch as a guiding principle. When analyzing situational awareness, the purpose of expanding the awareness of individual Soldiers is to achieve overmatch.

With the increase in technology, Soldiers are able to collect, package, and deliver information that was not available in the past. The main concern in regards to this new availability of technology is the fact that humans can only process a finite amount of information. A 2006 publication from the US Army Research Institute queried a panel of five retired military subject matter experts in order to identify 88 different types of key battlefield information streams that have a potential interest to squad leaders (Evans, 2006). The panel then created a Battlefield Information Questionnaire in order to gauge the relative importance of these different types of information to squad leaders in four tactical situations: planning before operation, assaulting an objective, consolidating and reorganizing on the objective, and defending the objective. The findings of the questionnaire gave an insight to the researchers to which information is pertinent to squad leaders on the battlefield. This study serves as the bedrock for the thorough understanding of what information is most important in facilitating the achievement of overmatch in ground combat.

Significant work has been compiled in the field of human decision-making in simulation models. A 2007 publication by James Moffat sought to more adequately model human-decision making in simulations in an effort to understand "how better information and a better approach to Command and Control (C2) lead to both better decisions and improved execution" (Moffat, 2007). In essence, Moffat used the principles of Bayesian decision analysis in order to create a decision modeling algorithm incorporating, among others, the subjective priority weighting of local effects in order to determine the utility of different courses of action. These local effects are best described as the relevant pieces of information in a combat scenario (Moffat, 2007).

There is a continuing rapid expansion of quantitative techniques for the analysis of economic, urban, social, biological, and other systems in which the animate behavior controls the system. In a publication by Lofti Zadeh on Human Decision Processes, it is contended that "The conventional quantitative techniques of system analysis are intrinsically unsuited for dealing with humanistic systems whose complexity is comparable to that of humanistic systems" (Zadeh, 1973). Zadeh's method of modeling human decision processes centers on the idea of fuzzy sets; a concept incorporating more qualitative variables characterized by gradual rather than abrupt changes. Though this work provides a compelling study of an alternate method of modeling human decision-making, its central position of utilizing 'fuzzy' sets and variables does not facilitate a realistic study for the intended scope. However, the explored logic provides an excellent roadmap for potential future work.

2. Methodology

2.1 Develop Combat Scenario Based on Activity Models

In order to create a consistent and reusable methodology for this study and future efforts, we focused on one specific combat scenario. This helps to scope the problem to a manageable size but also facilitates use with additional variations of common tactical scenarios, maneuvers, and decisions. Consider the activity model presented in Figure 2, which reflect a tactical 'React to Contact' scenario at the squad level. The leftmost diagram portrays the overarching scenario flow, with critical decisions reflected by diamonds. The 'call out' in the center of the diagram enumerates the specific elements of the leader's first principal decision in a reaction to contact: whether to attack or break contact. The initial reaction itself is a conditioned response that occurs reflexively at the individual level and therefore is ignored as a critical decision point. The 'Attack Battle Drill' diagram along the right side of Figure 2 illuminates the embedded detail and sub-decisions that emerge following the decision to attack. We chose the 'Attack' activity simply because it serves as the basis for almost all small unit infantry tactics. Thus, it allows for a broad and accurate depiction of common decisions made in combat.

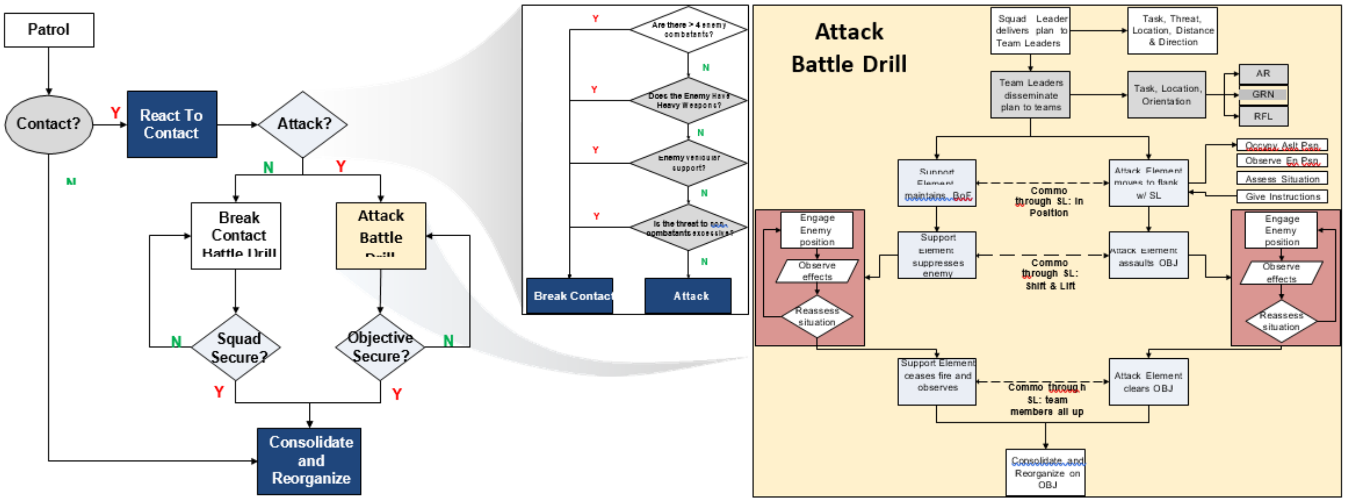


Figure 2. Squad-Level Patrol/React to Contact Activity Model

2.2 Determine Relevant Information Streams

Obviously, information is fundamental to acquiring any degree of SA. As previously noted, it is usually presumed that more information is better and will inherently lead to enhanced SA. However, as our stakeholders at the MCoE noted, the volume of information is secondary to getting the *right* information at the *right* times in the fight. Thus. The results obtained by Evans (2006) provided the basis for selecting the most critical streams of information necessary in a 'React to Contact' scenario. This study solicited input from former and current squad leaders to highlight the most and least important information streams in tactical scenarios. The study facilitators organized the information streams in three mission phases: planning, execution, and consolidation. Our work focuses primarily on the execution phase of the mission.

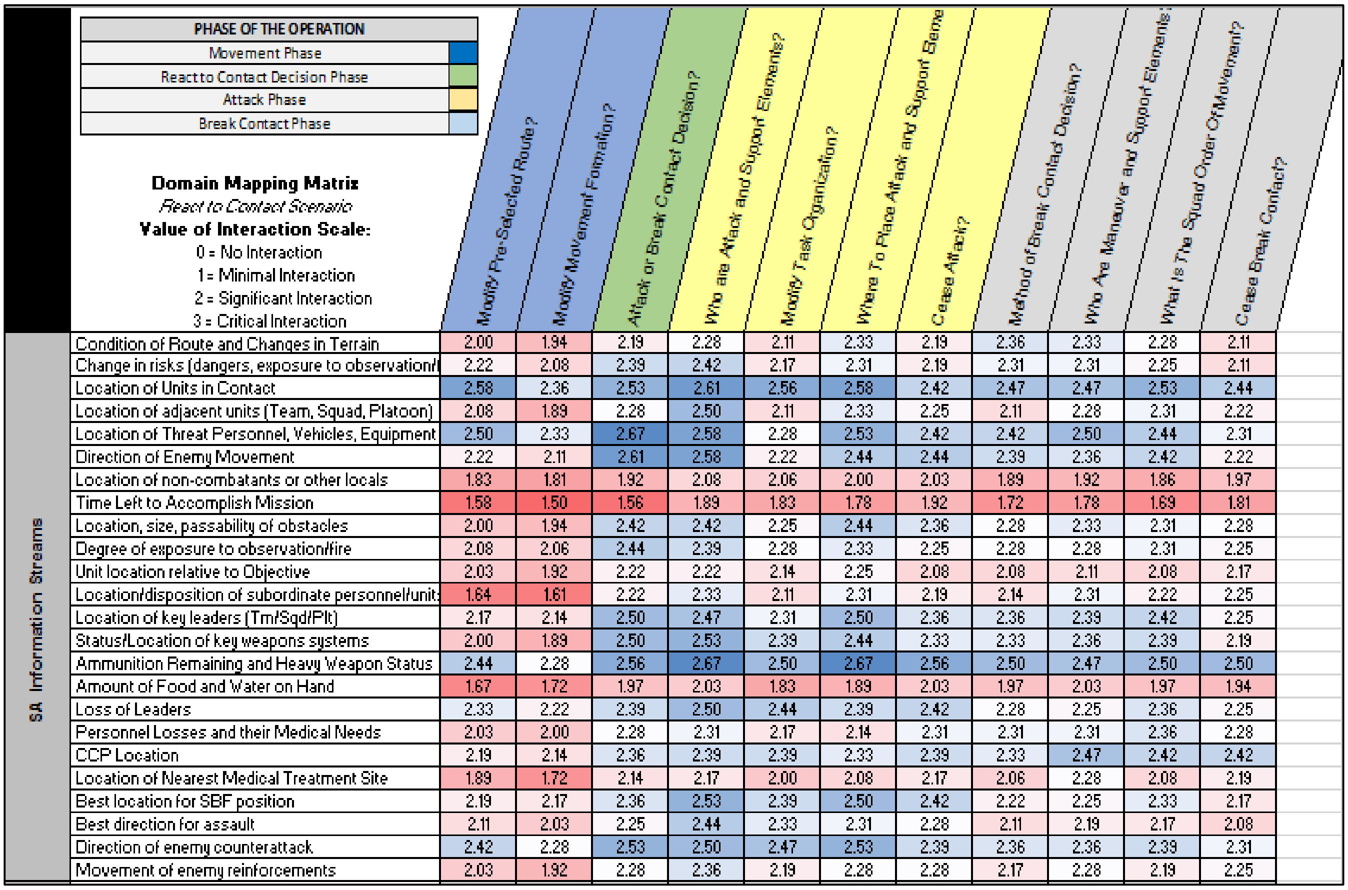
To develop a clear understanding of the interaction between each information stream and the various critical decisions within the operational environment, we developed a tactical vignette to survey key leaders at the platoon-level and below regarding their perceptions on the criticality of specific pieces of information. With greater than 35 responses from Team and Squad leaders and 35 more from platoon leaders from across the Army, analysis of their perspectives allows conclusions on each information stream's quantifiable significance in a tactical scenario. Additionally, it provides a deeper understanding of how leadership levels, experience, and position influence what pieces of information are most important to making decisions at critical points in the tactical scenario.

2.3 Mapping of Information Streams to Critical Tactical Decisions

Pursuant to identifying the critical information streams In order to better understand the level of interaction between the information streams and the combat situation, critical decisions in the scenario needed to be identified. We selected these decisions based on their potential impact on the outcome of the scenario. For example, the decision to attack or break contact represents a critical junction in the activity diagrams, shown in Figure 2.

A Domain Mapping Matrix (DMM) is a rectangular matrix that shows the relationships between two domains (such as people assigned to activities). A DMM does not show the relationships within either of the domains; it only shows the mapping between them. Danilovic and Browning (2007) reviewed several examples of such uses and codified DMM as an inclusive complement to Design Structure Matrices. DMM methodology enables the use of multiple domains for comparison and analysis. We used two domains: critical decisions and relevant information streams, which correspond to the columns and rows in Figure 3, respectively.

Before completing the final DMM survey design, a unique scale was necessary to quantify the level of interaction between the various discrete information streams and each critical decision. Scoring systems for DMM's are dynamic, and multiple different methods can be used to display similar information. For the purpose of this study, employing a numerical system was important. This 'Value of Interaction' (VoI) scale reflects the perceived level of interaction between individual pairings of each domain. The 0-3 scale allows for a simple and easily-understood scale to quantify the level to which certain information streams interact with specific decisions in the react to contact scenario. The VoI scale is shown in Figure 4.



PHASE OF THE OPERATION

Movement Phase	🟦
React to Contact Decision Phase	🟩
Attack Phase	🟨
Break Contact Phase	🟦

Domain Mapping Matrix
React to Contact Scenario
Value of Interaction Scale:
0 = No Interaction
1 = Minimal Interaction
2 = Significant Interaction
3 = Critical Interaction

		Modify Pre-Selected Route?	Modify Movement Formation?	Attack or Break Contact Decision?	Who are Attack and Support Elements?	Modify Task Organization?	Where To Place Attack and Support Eleme	Cease Attack?	Method of Break Contact Decision?	Who Are Maneuver and Support Elements?	What Is The Squad Order Of Movement?	Cease Break Contact?
SA Information Streams	Condition of Route and Changes in Terrain	2.00	1.94	2.19	2.28	2.11	2.33	2.19	2.36	2.33	2.28	2.11
	Change in risks (dangers, exposure to observation/f	2.22	2.08	2.39	2.42	2.17	2.31	2.19	2.31	2.31	2.25	2.11
	Location of Units in Contact	2.58	2.36	2.53	2.61	2.56	2.58	2.42	2.47	2.47	2.53	2.44
	Location of adjacent units (Team, Squad, Platoon)	2.08	1.89	2.28	2.50	2.11	2.33	2.25	2.11	2.28	2.31	2.22
	Location of Threat Personnel, Vehicles, Equipment	2.50	2.33	2.67	2.58	2.28	2.53	2.42	2.42	2.50	2.44	2.31
	Direction of Enemy Movement	2.22	2.11	2.61	2.58	2.22	2.44	2.44	2.39	2.36	2.42	2.22
	Location of non-combatants or other locals	1.83	1.81	1.92	2.08	2.06	2.00	2.03	1.89	1.92	1.86	1.97
	Time Left to Accomplish Mission	1.58	1.50	1.56	1.89	1.83	1.78	1.92	1.72	1.78	1.69	1.81
	Location, size, passability of obstacles	2.00	1.94	2.42	2.42	2.25	2.44	2.36	2.28	2.33	2.31	2.28
	Degree of exposure to observation/fire	2.08	2.06	2.44	2.39	2.28	2.33	2.25	2.28	2.28	2.31	2.25
	Unit location relative to Objective	2.03	1.92	2.22	2.22	2.14	2.25	2.08	2.08	2.11	2.08	2.17
	Location/disposition of subordinate personnel/units	1.64	1.61	2.22	2.33	2.11	2.31	2.19	2.14	2.31	2.22	2.25
	Location of key leaders (Tm/Sqd/Plt)	2.17	2.14	2.50	2.47	2.31	2.50	2.36	2.36	2.39	2.42	2.25
	Status/Location of key weapons systems	2.00	1.89	2.50	2.53	2.39	2.44	2.33	2.33	2.36	2.39	2.19
	Ammunition Remaining and Heavy Weapon Status	2.44	2.28	2.56	2.67	2.50	2.67	2.56	2.50	2.47	2.50	2.50
	Amount of Food and Water on Hand	1.67	1.72	1.97	2.03	1.83	1.89	2.03	1.97	2.03	1.97	1.94
	Loss of Leaders	2.33	2.22	2.39	2.50	2.44	2.39	2.42	2.28	2.25	2.36	2.25
	Personnel Losses and their Medical Needs	2.03	2.00	2.28	2.31	2.17	2.14	2.31	2.31	2.31	2.36	2.28
	CCP Location	2.19	2.14	2.36	2.39	2.39	2.33	2.39	2.33	2.47	2.42	2.42
	Location of Nearest Medical Treatment Site	1.89	1.72	2.14	2.17	2.00	2.08	2.17	2.06	2.28	2.08	2.19
	Best location for SBF position	2.19	2.17	2.36	2.53	2.39	2.50	2.42	2.22	2.25	2.33	2.17
	Best direction for assault	2.11	2.03	2.25	2.44	2.33	2.31	2.28	2.11	2.19	2.17	2.08
	Direction of enemy counterattack	2.42	2.28	2.53	2.50	2.47	2.53	2.39	2.36	2.36	2.39	2.31
	Movement of enemy reinforcements	2.03	1.92	2.28	2.36	2.19	2.28	2.28	2.17	2.28	2.19	2.25

Figure 3. Average Values for All Individual Non-Commissioned Officer Inputs into the DMM

The two domains allowed creation of the matrix from which we could effectively map what factors affect certain situations. The critical decisions domain focused specifically on the physical situation (i.e. patrolling, react to contact, etc.). The relevant information stream domain, on the other hand, focused specifically on certain aspects of a Soldier's surroundings (i.e. ammunition remaining, direction of enemy movement, etc.). The two domains work together to paint a picture of how a Soldier thinks and behaves in certain components of a combat patrol. For example, a Soldier may care less about a casualty collection point during a patrolling exercise than he or she would when in contact. This is proven by the survey compiled from the officer and enlisted personnel.

Once we compiled both domains, we then created a usable application to facilitate the collection of data from test subjects, which serves as the basis for our analysis. The application takes the user through a demographics survey, an explanation of the tactical scenario, a set of directions, and a fillable DMM relating both of the discrete domains. The application is designed so that upon completion by a test subject, the saved Excel File will contain both the filled DMM and a compiled demographics profile for analysis. Figure 4 depicts the resulting DMM for NCO responses; a similar matrix was created for officer responses.

3. Analysis and Conclusions

The analysis of the data revolves primarily around the input of officers and enlisted Soldiers. The data collected to run the analysis consisted of 33 non-commissioned officers. Compiling into a single file consisting of all the soldiers' submissions were each data set from the individual Soldier. The survey results allowed for calculation of averages and standard deviations at each discrete domain. Once compiled, grouping the most critical information streams together into five categories representing each phase of the scenario was necessary and important: Patrol, React to Contact, Attack/Break Contact, Attack, and Break Contact. The averages coupled with the standard deviations of each information stream made it possible to identify potential information streams most needed for the modern Soldier.

Figure 3 illustrates the averages produced from the surveys completed and uses a specific color scheme to propagate the chart. The more blue the square, the higher the value which translates to a more important information stream during a specific phase of the operation. Conversely, the redder the square, the lower the value and thus, the less important the information. A vast majority of blue cells within a column indicates that the survey respondents believe that a particular phase of the operation acts as a critical time for information streams, relative to other columns. In contrast, a majority of blue cells across a row indicates a particular information stream is considered critical information throughout all phases of operations.

Thus, it is possible to determine that the [Attack or Break Contact Decision?] and [Who are Attack and Support Elements?] are the most critical decisions within the operation for information streams to flow. Using the same method, the two most consistently critical information streams across an entire operation are [Location of Units in Contact] and [Ammunition Remaining and Heavy Weapon Status]. This realization indicates that any enabling technology fielded to Soldiers should consider inclusion on software capable of sensing and reporting these information streams to the end user. The power of this Figure is the quantification of criticality between information streams and decisions in the tactical scenario. This relationship indicates which information streams should be required at each mission phase to make the most logical and sound decisions.

Through a pessimistic lens, applied by viewing red cells rather than blue cells, it is possible to determine which phases and information streams are of marginal importance when compared. This too proves powerful to relevant stakeholders, as it may explain which information streams may be over-valued by enabling technology developers. Figure 3 portrays the average values and standard deviations for two select information streams. The lines represent the averages for the "ammunition remaining" and "time to accomplish the mission" information streams. These two streams are the maximum and the minimum scoring information streams, respectively. The error bars, located vertically at each decision point within the scenario, represent the standard deviations for each information stream. The larger the error bar, the more deviation from the mean.

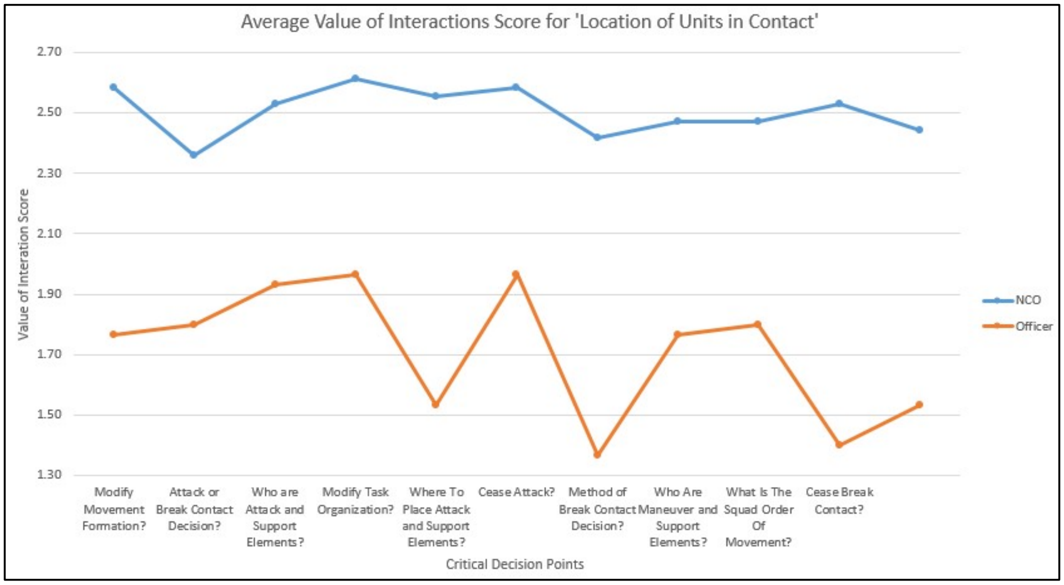


Figure 4. Value of Interaction Averages

Figure 4 shows the complete results for NCO and Officer averages based on the NCO's highest-scoring information stream which is "Location of Units in Contact." It is immediately apparent that the NCO average is greater than the Officer average by roughly 0.80. What can be gained from this information is the similarities and differences between the two demographics. If both lines decrease in value from one phase to the other, it can be concluded that the previous phase is more important than the immediate phase. For example, "Cease Attack?" has a higher value than "Method of Break Contact Decision?" in both line graphs, leading to a conclusion that "Cease Attack?" is a more important phase of the operation than

"Method of Break Contact Decision?" However, more analysis will be conducted on phases where the NCO or Officer increase/decrease while the other line does the opposite.

It is important to note that sample bias could negatively impact the accuracy of the data we collected. Therefore, the results of this survey will require systematic testing to ensure a large enough sample size was used. The demographics component of the survey will aid in identifying any potential underlying biases. The results of our testing can also be split into areas of operation to better fit test subjects environmental preferences if the data lends itself to these subdivisions. Essentially, the question centers on the sources of variation in the multitude of survey responses. As is critical in all major collections of data, this methodology seeks to source and identify the relevant characteristics that may impact the responses derived from each test subject. In order to better understand how demographics impact the value of information, a series of officers roughly thirty Officers will be analyzed using the same methodology. Their compiled results will be used to illustrate how the value of information changes at each decision point. In this comparison, the value of information will be averaged at each decision point in both the Non-Commissioned Officer and Officer Domain Mapping Matrix.

4. Future Work: Decision Modeling

The current effort naturally flows into the next and more analytical line of work. In the present state, this study allows for the identification and prioritization of the most critical information streams at each decision point of a 'React to Contact' tactical scenario. This conclusion is based upon the methodology and survey results delineated in previous sections. Moving forward, the desire is to translate the results of this effort into a decision model capable of adequately representing the agent-based decision making process in a combat simulation. In effect, this advanced decision model will apply the quantified decision streams to a weighted factor scoring model which can analytically determine which course of action an agent will follow at various decision points. This is a major advancement from existing decision models utilized in simulations throughout the military realm. Where many combat simulations concretely program the nature of decision making, this updated model will provide a more accurate representation of human decision making. In relation to the overarching goal of this expansive study, a decision model incorporating the determined value of information (VoI) will facilitate the analysis of operational benefit resulting from enhanced situational awareness. The basis for this updated decision model is shown in Figure 5. The depicted figure centers on the concept of 'Course of Action' utility derived by James Moffat. In essence, the enhanced decision model will be able to analyze the utility of choosing a course of action for a given decision point. Figure 5 shows a generic example of a decision point at which the decision maker is faced with two courses of action, ***a'*** and ***a"***.

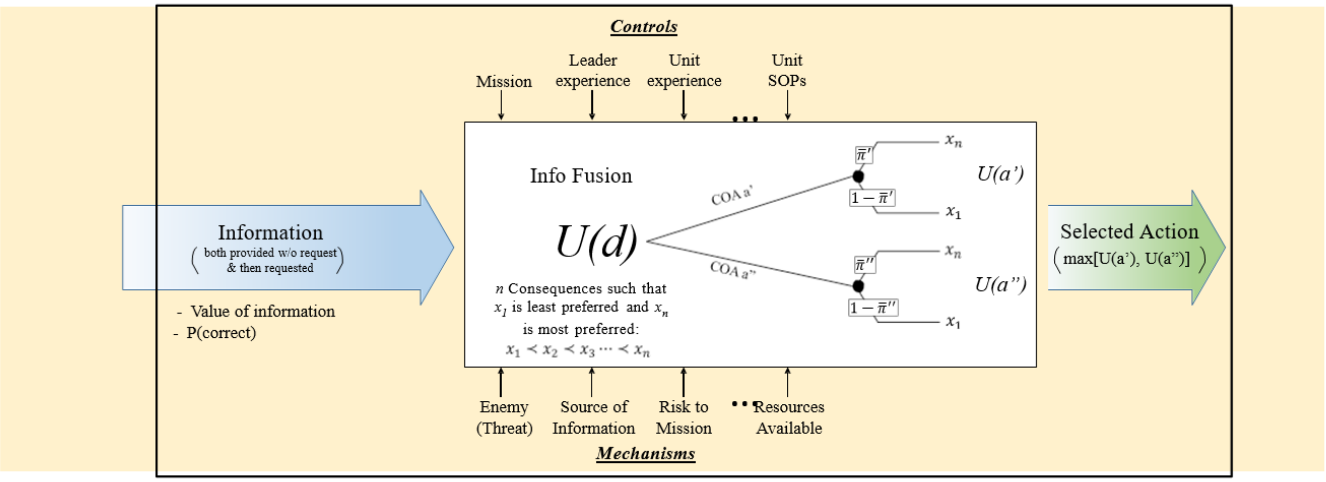


Figure 5. Decision Model Reflecting the Fusion of Information, Controls, and Mechanisms to Generate a Utility-Based Course of Action (COA) for a Specific Decision in the Tactical Scenario

As reflected by the tree, the value of a given stream of information, derived from the DMM, serves as the primary input to the decision model. Some of this information will come in unsolicited (bottom-up based on the situation, unit procedures, etc.). If a disparity exists between what was provided and what is required for the decision, additional information will be requested to close the gap. As shown by equations 1-3, the quantified information forms the first component of the individual utility functions for COAs ***a'*** and ***a"***. The various controls and mechanisms supplement and interact with the information, influencing the process by which the leader fuses the information to derive utility. The decision tree evaluates all available COAs by comparing their individual utility functions and selecting the one with the highest utility for the simulated agent's situation. Future work will allow for the determination of probabilities associated with each course of action in a decision. This enhanced decision model will allow a simulated agent to make the most effective decisions in a combat scenario, based on the value and relevance of collected information, while also incorporating the utility of a course of action. This critical step will allow for the determination of whether situational awareness translates into operational benefit.

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6. References

Danilovic, M., & Browning, T. R. (2007). Managing complex product development projects with design structure matrices and domain mapping matrices. *International journal of project management, 25(3),* 300-314.

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37(1),* 65-84.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37(1),* 32-64.

Evans, K. L. (2006). *What squad leaders want to know in battle*. Army Research Inst For the Behavioral and Social Sciences Fort Benning Ga.

Mundweil, P. J. (2013). *Overmatch: Enabling the Infantry Rifle Squad as the Foundation of the Decisive Force* (No. ATZL-SWV). Army Command and General Staff College Fort Levenworth KS School of Advanced Military Studies.

Zadeh, L. A. (1973). Outline of a new approach to the analysis of complex systems and decision processes. *IEEE Transactions on systems, Man, and Cybernetics, (1),* 28-44.