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A Systems Approach to Battle Management Aids

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Abstract

The ability to optimally manage distributed warfare assets for collaborative operation significantly increases our military advantage. Recent studies have pointed to an increasing speed of warfare, emerging threat capability and numbers, and data overload from a growing number of sensors and networks. This results in challenges to human decision making when faced with a complex decision space, multitudes of information, and the fast reaction time required. Automated Battle Management Aids (BMAs) have the potential to reduce timelines, increase decision confidence, and optimize warfare resources. This paper describes a systems engineering approach to conceptualizing and designing BMAs for future Naval and Joint warfare missions. A systems approach views BMAs holistically in the context of capability enablers for managing future distributed warfare assets as Complex Adaptive Systems of Systems (CASoS).

I. Introduction

Tactical warfare is complex (Bar-Yam 2004). It requires agile, adaptive, forward-thinking, fast-thinking and effective decision-making. Advancing threat technology, the tempo of warfare, and the uniqueness of each battlespace situation, coupled with increases in information that is often incomplete and sometimes egregious; are all factors that cause human decision-makers to become overwhelmed (Zhao et al. 2015). Automated BMAs become a solution to address this complexity—to simplify complexity, to increase understanding/knowledge, and to provide quantitative analyses of decision options.

Automated BMAs are computer-aided decision support systems that are meant to enhance and improve tactical decisions. BMAs may improve decisions by: speeding up the decision process; providing greater confidence in the knowledge that decisions are based on; developing more decision options; providing greater understanding of decision consequences; developing options with greater probability of success; and/or improving the optimization of resource usage. The military currently uses BMAs to share and process data to develop operational pictures and situational awareness. However, this paper is focused on conceptualizing BMAs as envisioned for the future for Naval and Joint operations.

A systems approach integrates the analytic and synthetic methods, encompassing both holism and reductionism (Checkland 1993). It emphasizes the interdependencies and interactions between elements within a system and between systems and their external environments (Gharajedaghi 2011). This paper proposes the necessity of following a systems approach for the conceptualization and engineering of future automated BMAs. The paper first characterizes tactical decisions and the possible role of future automated decision aids. It then proposed a systems approach to this complex problem space.

II. Decision Aids for Battle Management

As preparation for conceptualizing automated BMAs, this section characterizes the types of decisions made for battle management. It discusses how BMAs may be used to support human decision-makers within a military tactical environment. Finally, it introduces the concept of "decision complexity" and the role of BMAs to manage and address tactical complexity.

A. Battle Management Decisions

Military tactical operations involve a great variety of battle management decisions. Most decisions involve the use or placement of warfare assets which include platforms (ships, aircraft, submarines, etc.), weapons, sensors, communication devices, and people (Johnson, Green, and Canfield 2001). Figure 1 illustrates four domains of warfare decisions: the temporal domain, the spatial domain, the proactive/reactive domain, and the domain of rules and policies. Each of these domains affects the decision-making process and can lead to increased decision complexity.

Planned or proactive decisions include positioning forces (ships, battlegroups, aircraft, etc.), stealth operations, offensive attacks, and denying enemy operations through jamming or other force measures. Examples of reactive or responsive decisions include defending against an active threat, moving platforms into a defensive posture, retreating from a threat environment, and assessing battle damage. Effective battle management must recognize when proactive or reactive decisions need automated support.

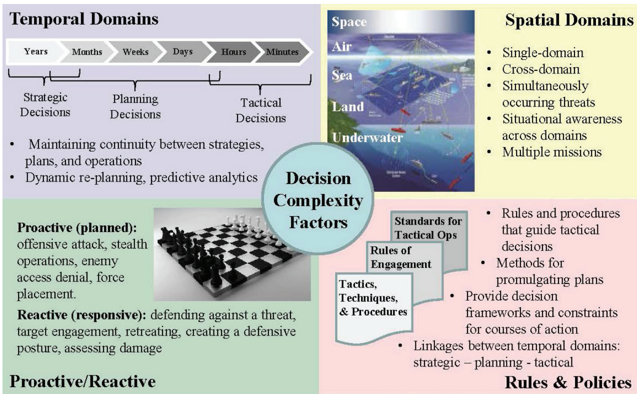

Figure 1 – Tactical Decision Domains

The nature of military decisions shifts over time and can be viewed as hierarchical. Strategic decisions have a longer time horizon and consider high level objectives—sometimes spanning years. Planning-level decisions have a shorter time horizon and are proactive even when arranging a defense. Tactical decisions, which are the main focus of battle management, have the shortest time horizon and involve very near-term planning or proactive decisions as well as reactive decisions in response to enemy actions. Consistency is desired among the three temporal decision domains to effect compatibility among tactical, planning, and strategic decisions. Likewise, plans and strategies need to support effective tactical warfare and reflect major changes in tactical threat environments. Automated BMAs should be designed to support a hierarchical decision paradigm as well as one that supports and adapts to varying decision time horizons.

One of the results of the hierarchical temporal decision domain is a set of rules and policies that guide tactical decisions. These rules are one of the methods by which near-real-time decisions can align with longer term plans and strategies. The rules and policies support effective tactical decisions that are consistent with the higher objectives. Automated decision aids could support dynamic and adaptive decision-making across the temporal and hierarchical domain to enable consistency among levels; consideration of how changes at various levels might affect other levels; and effective promulgation of guidance across levels.

A fourth way to categorize battle management decisions is by spatial domain; such as space, air, sea, underwater, and land. Threats vary greatly in each of these operational environments. Likewise, warfare systems are developed to address specific threats or threat types which naturally reflect their spatial environment. Naval battlegroups must address threats in all spatial domains, and at times, simultaneously. Automated BMAs have the potential to address this complexity through gains in cross-spatial-domain situational awareness and through the development of decision alternatives that prioritize missions and engagement strategies.

Ultimately, the battle management decision space fluctuates from simple to complex as operations range from peacetime to multi-domain threat encounters. Examples of changes to the problem space that affect the complexity of the decision space include: battle tempo (or reaction time), the number of simultaneously-occurring threats (or battle events), the severity of the consequences of battle events, the heterogeneity of threats (due to threat type or spatial domain), and the scope of the event or events (in terms of area or population affected). All of these operational factors translate into multi-dimensional variables that comprise a "decision space." As the decision space complexity increases, military human decision-makers may become overwhelmed. At this point, having automated BMAs in place, can support effective decision-making.

B. Automated Aids to Support Human Decisions

The amount of information in the battlespace has increased due to more sensors, networks, participants, reach-back and intelligence. Human decision-makers become overwhelmed with information and shortened decision times. Automated BMAs are a necessary capability required for effective tactical decision-making.

Automated decision aids, or "machines," as depicted in figure 2, can support human decision-makers in a number of ways. Three models for human-machine decision-making interaction are shown (Johnson, Green, and Canfield 2001). The manual decision-making model encompasses situations in which humans collect and "store" relevant information as well as perform the decision analysis (processing and decision-making), in their heads. This model implies a fairly simple and straightforward decision space in which the amount of data and number of variants is manageable manually. In the semi-automated model, the human decision-maker can rely on machines to manage, store, fuse, and process the input information to display decision analytics to the human. Decision analytics may consist of knowledge of the battlespace and threats, course-of-action (COA) options, and quantitative measures of expected event successes and consequences. Finally, in the fully automated model, the role of the human is to monitor the automated machine decision processes and to override or change decisions when necessary.

It is important to establish the appropriate mechanism for the type of decision being made. In general, decision-making can be performed manually when the problem space is relatively simple and the number of factors to be considered and the amount of information is manageable by the human decision-maker. For some types of decisions, a semi-automated HMI mechanism is most appropriate. This is effective for more complex decision spaces with potentially critical or dire consequences; requiring the support of automated BMAs, but with significant human involvement. A fully automated human-machine interaction is appropriate for decision spaces that are complex in terms of large amounts of information that must be processed and fused; but very straightforward in terms of the types of decisions being made. Fully automated decision modes are for peacetime operations where decisions do not have dire consequences or for highly complex operations where the decision reaction time is too compressed for humans. Fully automated decision modes are appropriate when there is very high confidence in the information and knowledge of the situation. For example, when it is known with high confidence that a tracked object is in fact an enemy threat target.

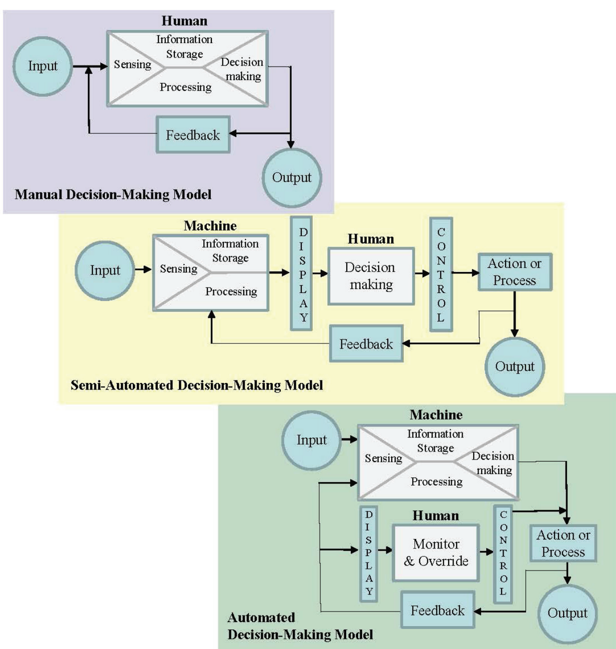

Figure 2 – Human-Machine Models for Decision-Making

A future goal for battle management decision support systems is to have the capability to select the appropriate decision model for the given decision space. Perhaps a flexible decision-making architecture can accommodate all three human-machine models and apply them as needed. The superstructure, itself, would be monitoring the decision space and evaluating what kinds of decisions needed to be made and then determining the appropriate interaction between the human and machine to make each decision.

C. Battle Management: A Complex Endeavor

Battle management operations are complex (Young 2012). The tactical environment can range from peaceful to highly dangerous as shown in figure 3 with a multitude of varied threats from many different directions. This translates into a complex decision space for battle management. The "state" of the decision space must flexibly shift from linear and straightforward during normal non-threat operations, to highly nonlinear and multi-varied during combat operations.

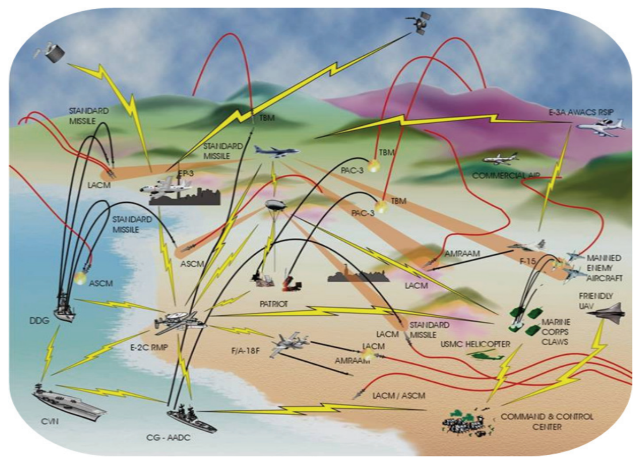

Figure 3 – Battle Management in a Complex Tactical Environment

Characteristics of a complex problem space include: complex objectives, complex environments and/or operations; adaptation; collective behavior; and unpredictable outcomes of decisions. Each of these characteristics are inherent to tactical operations (Young 2012). The battlespace presents multiple objectives that are generally inconsistent and changing. Military systems must weigh their individual battle objectives, such as self-defense, against force-level missions which may include area defense, stealth operations, or defense of specific assets. Complex operations are required as adverse and widely varying environments result in changing target priorities and multiple cross-spatial domain missions. Adaptation is a required characteristic of warfare systems as they respond to the complex and changing threat environment. Military operations must adapt effectively to threats to improve their chances of survival and meet tactical and strategic goals. The collective behavior of distributed warfare assets must be properly orchestrated to avoid collisions and friendly-fire incidents; and ideally benefit from their cumulative contributions. Finally, the unpredictable outcomes of tactical decisions ranging from misfires to misidentifications to mis-assessments of battle damage, result in a problem space made more complex through inaccurate knowledge and a ripple effect of actions and unforeseen consequences.

Automated BMAs have the potential to support human decision-makers by characterizing the level of complexity in the operational environment and translating this knowledge to the decision space. Ideally, a complete and accurate "picture" of the battle space will provide situational awareness to the decision space. BMAs could monitor the picture and develop assessments of the complexity characteristics of the problem space. This knowledge could support effective and timely use of decision aids as well as enable the effective interplay of human and machine decision-making.

III. A Systems Approach

"…only complex systems can perform complex tasks (Braha 2006)."

Bar-Yam writes that "…a high complexity task requires a system that is sufficiently complex to perform it (Bar-Yam 2004)." Tactical military operations present highly complex environments that translate into complex tasks that warfare assets must perform. This section explores a complex systems approach to implementing automated BMAs into military operations to effectively address tactical problem spaces.

The previous section characterized the battle management problem space in terms of decision-making; made the distinction between decisions made by humans and how automated decision aids can support those decisions; and characterized battle management complexity. This section introduces a way of thinking about the problem space as a means to conceptualize and ultimately implement a systems solution.

A. Viewing Warfare Assets as Resource Systems

The first step in a systems approach is to "view" the problem and solution spaces in terms of systems. For tactical warfare, this begins with viewing warfare assets as resource systems. Defining assets (such as: ships, aircraft, submarines, weapon systems, sensors, communication devices/networks, and jammers) as systems, allows them to be considered as resources and viewed in terms of their functions, performance, behavior, structure, and interfaces. It enables quantitative analyses to be performed based on their characteristics such as location, status, and expected capabilities. As operations grow in complexity, automated BMAs could perform analyses to determine the effective use of warfare resources when multiple objectives exist that overlap and conflict. Warfare resource utilization could, with the aid of BMAs, include forming collaborations among systems to enable system of systems behaviors and capabilities to better address complex tactical missions. Figure 4 illustrates a networked collaboration of warfare assets shown as a system of systems.

"Multidimensionality is probably one of the most potent principles of systems thinking. It is the ability to see complementary relations in opposing tendencies and to create feasible wholes with infeasible parts (Gharajedaghi 2011)." By viewing the battlespace as a set of interacting systems, the ability to exploit their multidimensionality supports collaborative force-level behavior that spans spatial and temporal domains. It enables layered defense and integrated fire control strategies involving distributed weapons and sensors. Automated BMAs can provide the quantitative analysis to determine collaborative resource utilization when complex multidimensional objectives exist.

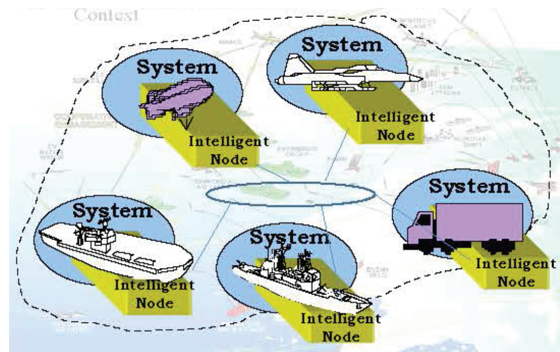

Figure 4 – Warfare Assets Viewed as System Resources

B. Viewing Battle Management Holistically

Complex tactical environments require a holistic perspective to manage warfare resources from a force level. As the environment becomes more complex, events are occurring more rapidly and in parallel. The numbers of decisions are increasing as are the number of courses of actions required. More demands are being made on the finite set of warfare resources and their missions, objectives, and courses of action are becoming more interrelated. Gaining a "holistic" understanding of multiple threats and missions as well as the possible options for addressing them as well as the possible consequences provides a more effective military response and may be required to effectively address demanding threats. The idea of battlespace perspective can be characterized as "decision scope," or setting a boundary around the problem space and solution space. A more holistic decision scope includes an area or theater and all threats and warfare resources in this geospatial area. A narrower decision scope may only include a particular threat and a particular platform and its associated assets.

Establishing decision scope is both a limiting factor and a necessary enabler. Tactical decisions become more interdependent and "messy" in terms of cause and effect as the operational environment becomes more complex (Jackson and

Keys 1984). Making a particular weapons engagement decision or sensor tasking decision is simpler when there is one threat to kill or one area of interest to view. However, narrowing the decision scope to firing a single weapon system or managing the sensors on one ship, loses its overall force-level effectiveness when several tactical missions need to be addressed or many threats need to be prioritized and engaged. The principle of "holism," applied to decision-making in this context involves including "simultaneously and interdependently as many parts and levels of the system as possible (Jackson and Keys 1984)." In other words, widening the scope of the decision space to perhaps consider a tactical area or theater. Determining the decision scope is a decision in itself. The goal is to design future force architectures that support a flexible decision scope that can widen as force-level missions become more complex and might benefit from distributed warfare asset collaboration.

Once a tactical military force faces a complex operational problem space, future automated BMAs could establish a more holistic and wider decision scope and support resource management at both the platform and force levels. Ultimately a variety of automated BMAs could support resource usage at different levels. BMAs supporting specific sensors and weapons could be orchestrated by a higher level BMA architecture. Thus a system of BMA systems could be implemented.

C. Viewing the Decision Space as a System

The "decision space" can be viewed as a system. By taking a systems approach to the decision space, it enables the definition of a boundary, inputs and outputs, functionality, performance, and structure. Figure 5 illustrates the decision space in its contextual environment. Knowledge (or situational awareness) of the battlespace is developed and maintained as the "problem space" (or operational tactical picture). It includes tracked threat objects as well as terrain, weather, defended assets, and all other physical entities in the real world. A "resource picture" must also be developed and maintained that includes up-to-date status, health, readiness, and projected capabilities of the warfare assets. The problem space and resource picture comprise the primary inputs to the decision space.

The boundary of the conceptual decision space system surrounds the decision architecture, and the decision analytics which include decision aids, assessments, prioritizations, alternatives generation, and overall decision management. The primary function of the decision space system is to develop decision alternatives. These alternatives provide recommendations to manage the warfare resource assets. Examples include sensor tasking, courses of action, weapon scheduling, the movement of platforms (ships, aircraft, etc.). Secondary functions include estimating the confidence levels associated with decision alternatives and the many types of analyses that feed into the alternatives. Examples of analyses include: prioritizing threats, wargaming possible consequences, estimating sensor error, estimating knowledge accuracy and completeness, evaluating operational complexity, recommending optimum human-machine decision-making interaction. The interaction between the human and automated decision space is not illustrated in the simplified concept shown in figure 5. But this interaction would be significant in tactical operations.

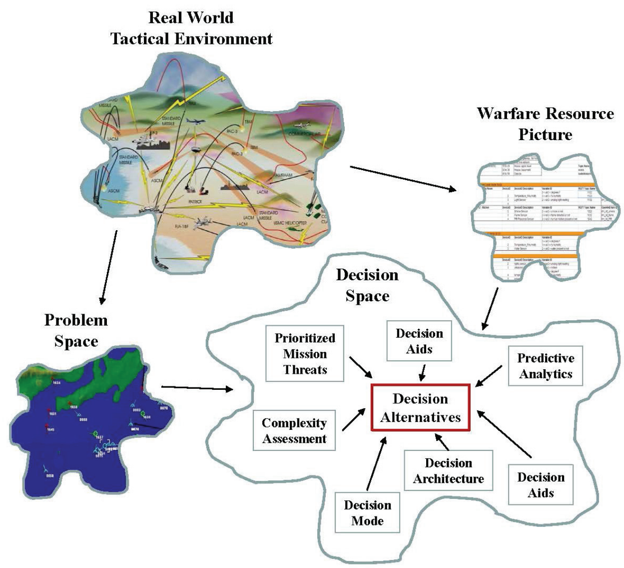

Figure 5 – Mappings into the Decision Space

The outputs of the conceptual decision space system could include decision alternatives, estimations of predicted consequences, estimated probabilities of success and failure; and confidence levels associated with source information, options, and knowledge in general.

D. Solution Space: Complex Adaptive Systems of Systems

A final step in this overview of a systems approach to BMAs, is the conceptualization of the solution space. With a goal of enabling a tactical response to a complex threat space, the solution space consists of the effective use of distributed warfare assets/resources. The solution must change in time and adapt as the threat environment changes. At times an offensive action is the best option, at other times a single platform can address the threat, and yet at other times, a multitude of offensive, defensive, collaborative, and autonomous actions may be required, both parallel and in series. The ability of the solution space to shift seamlessly from simple to complex operations, thus changing the nature of its system state, is a challenging requirement.

This paper conceptualizes the solution space as a complex adaptive system of systems (CASoS) (Glass 2011) in which the distributed warfare resources interact as systems of systems, exhibiting emergent (force-level) behavior, and adapting to the changing operational environment. This class of systems is a required solution to effectively address complex tactical problem spaces. Engineering future warfare systems to behave as CASoS requires a decision architecture and solution space of automated BMAs that provide the following three capabilities (Johnson 2017):

1. Adaptive relationships—An adaptive intelligent architecture enables agile interrelationships among the constituent systems that comprise an ultimately adaptive SoS that can respond to a changing complex environment.
2. A system of intelligent constituent systems—The adaptive emergent behavior of the CASoS is governed by the self-management of the distributed constituent systems to collaborate or act independently as the complex situation dictates.
3. Knowledge discovery and predictive analytics—Key to the engineered CASoS is the ability to gain and maintain shared situational knowledge of the environment and the distributed constituent systems. The knowledge is analyzed to prioritize missions; develop tasks and courses of action (adaptive responses to the problem space); and to develop "what-if" and "if-then" predictive scenarios to shape the synthesis of future intelligent decision and adaptive SoS relationships.

The decision space must support the conceptualized CASoS solution space. The decision space for this complex application can be thought of as a system of BMA systems with holistic force-level management decision aids supporting the orchestration of lower-level BMAs concerned with specific resource or platform systems. The holistic-level BMAs could manage the problem space information and focus on high-level concerns such as evaluating the level of complexity, establishing decision scopes, and recommending human-machine decision interactions. All of this requires automated BMAs, an adaptive architecture, warfare resources that are "taskable," and a command and control culture that supports this systems approach.

III. Conclusions

In summary, the battle management problem space is complex and will only continue to grow in complexity with the addition of more sensors, more information more unmanned threats, more non-state adversaries, and advances in technology. To stay ahead of this problem space, a complex solution space must be conceptualized and eventually realized to facilitate fast-acting and highly responsive warfare utilization. A systems approach provides a method for addressing the multidimensional and adaptive decisions required by offering holism, a systems perspective and the definition of the decision space as a system of systems. It frames the problem as a CASoS and highlights the need for a decision architecture that enables adaptive relationships, intelligence at the system level, shared knowledge, and predictive analytics. The effective use of automated BMAs in support of human decision-making provides the foundation for the CASoS solution space.

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