Re-characterizing Goals, Objectives and Metrics to Support Application of Advanced Analytical Technologies in Military Command and Control

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Abstract

Advanced command and control technologies offer significant enhancements to the ability to perform at the tempo required by modern day crisis operations. A measurable portion of current Department of Defense information technology research focuses on an even larger future role for technology in military command and control. Some visionaries see the command and control structure of the future as consisting of men and machines integrated into a series of cyborg clusters. Others see an environment where geographically dispersed machines will come together to form virtual command and control environments. Fewer humans will be required in a supervisory role. Before these or any other visions of the future can be implemented, two key questions to be answered:

- "What are the proper roles for men and machines in the military command and control structure of the future?"
- "What fundamental changes are necessary to the business rules, information flow and representation, and processes currently in use?"

This paper will address the second part of this question with a focus on the issues concerning decomposing objectives into tasks, placing a relative value on each task to reflect current priorities, and establishing metrics to allow technology components of the command and control structure to assist in battle management.

1 The Problem

Modern information technology components offer unprecedented speed in the delivery and processing of data. Information fusion concepts are improving the speed that data becomes meaningful information. We are becoming increasingly reliant on technology to allow the military decision maker to keep pace with the tempo of modern warfare. The United States Joint Chiefs of Staff, in Joint Vision 2020 state that the focus of the vision is "Full Spectrum Dominance"[1]. This document highlights the fact that attainment of the goals set forth in Joint Vision 2020 will require, "the steady infusion of new technology…"[2]. The Joint Chiefs go on to warn that "advances in information capabilities are proceeding so rapidly that there is a risk of out stripping our ability to capture ideas, formulate operational concepts, and develop the capacity to assess results."[3]

Much of the focus for recent information technology developments has been on a tighter coupling of sensors and shooters. The "Sensor to Shooter" concept focuses on getting information rapidly from the systems that identify specific threats and targets to the units tasked with the prosecution of operations however, the descriptions often fail to include a critical element, the decision maker. The decision maker must continue to be an integral part of the command and control process either through direct involvement or, through decision support technologies. As the tempo of military operations continues to increase, one needs to apply technology to assist the decision maker filter the available sensor information, identify those critical elements of information, reach a decision and then disseminate guidance to all subordinate units. Technologies are becoming available that can assume responsibility for many of the decisions required. These technologies can select from among alternatives if the commander's intent, expressed in clear, unambiguous terms, provides the basis for the selection. The key is to know where and when to apply automated decision support technology.

2 Relevance to the Command and Control Environment

As one looks for new roles for technology in the command and control there is a need to analyze the workflow, process and decision models constructed to represent the command and control environment. One also needs to define and understand the business rules that govern decisions and how various factor, either alone or in combination with other factors, influence the application of those rules. The Air Force Scientific Advisory Board identified the key elements of dynamic command and control as, "knowledge of the adversary, real-time knowledge of the battle space, distributed knowledge of the commander's intent, decentralized execution, dynamic

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[1] Joint Vision 2020, Joint Chiefs of Staff, 2000

[2] Joint Vision 2020 p3

[3] Joint Vision 2020, p8

control of sensors and shooters, and real time assessment of the effects".[4] The Scientific Advisory Board goes on to highlight the need for improved understanding to support a fast-paced, dynamic decision process. One of the more prophetic observations of the Science Advisory Board is captured in a quote from Albert Einstein. Dr Einstein once said, " The world we created today has problems which cannot be solved by thinking the way we thought when we created them."[5]

Clearly, there is a need to think about new and more dynamic methods to employ the art and science of command and control. Research underway at the Military Service Battle Labs and the Defense Advanced Research Project Agency (DARPA) are exploring new technologies and concepts for command and control that range from the tactical level all the way to providing strategic direction.

The need for speed and accuracy in decision-making places a premium on information technologies and advanced, high speed, reliable communications. These tools of modern command and control also pose a significant vulnerability. An enemy can disrupt communications channels. Computers and computer networks are also subject to attack and disruption or deception. Command and control structures must take advantage of the benefits of information technology and communications. At the same time, our command and control processes cannot be crippled when data dissemination is impaired. This requires a detailed analysis of command and control requirements, the processes that support these requirements and, the structure of the information flowing through the command and control environment.

Conceptual Models of the Mission Space (CMMS) are being developed to describe the nature of command and control. This blending of Business Process Re-engineering and the Unified Modeling Language (UML) hold tremendous promise for helping us understand and model command and control processes as the first step toward applying automated, distributed decision support technologies. These approaches are best suited for micro-analysis of individual command and control processes and not for the macro-level analysis of the enterprise. The reason is that these methodologies tend to look at the command and control environment from a single perspective. Additionally, they tend to look at the textbook process where information flows into the model and a product flows out. The military operations domain is a dynamic environment where actual events often deviate from plans. How

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[4] United States Air Force Scientific Advisory Board, Report on Air Force Command and Control: The Path Ahead, Volume 1 Summary, December 2000, p 2.

[5] Ibid, p1

the system responds, the communications among the various functional and organizational nodes and the balancing of conflicting priorities is part of the fabric that makes up the macro level command and control tapestry.

If the CMMSs represent the micro level approach then the next step is to find methodologies that address the enterprise issues to convey the full richness of this dynamic, interactive command and control environment.

The previous paragraphs identified the need to build command and control systems that leverage the capabilities of advanced information technology and communications to support today's operational tempo. It also briefly touched on the need to develop processes that can survive when an enemy attacks the systems providing information technology and communications. These two factors would suggest that decision support technology be distributed to provide local autonomy while maintaining overall synchronization of the operation. The issue is distributed control of military operations and how information objects are structured to facilitate the use of both human and automated control mechanisms.

3 Automating Command and Control Processes

Automating command and control processes effectively requires more than just applying technology to "speed up" current processes. Sensor to shooter concepts must incorporate decision making into a conceptual framework that identified the specific decision characteristics needed. Both human and automated decision making methodologies must be considered when developing the integrated command and control system. A key element for this integration is determining where automated decision tools belong.

Three areas where advanced automated decision support technologies can potentially aid the military decision maker are: strategy to task decomposition, automated task scheduling, and performance assessment. Each of these areas carries specific requirements for information structure and format. Each technology also requires that military decision makers alter their concepts for characterizing their concept of operations and for adjusting the operation in response to events.

These applications of technology can also be self-regulating if the rules guiding the decision process are specified with sufficient detail and a set of meaningful metrics can be defined so that progress can be accurately tracked.

3.1 Strategy to Task Decomposition

Artificial Intelligence, coupled with hierarchical task structures and a domain specific knowledge base offers one means to automate the strategy to task decomposition process but there are significant challenges in applying the technology. The first is creating the knowledge bases that will form the basic building blocks for decomposition. In combat air operations, there are several instances where high-level goals such as "Gain and Maintain Air Superiority" translate into a set of specific target types such as radars, surface to air missile sites, and bases supporting air-to-air capable fighter aircraft. The types associated with each template are compared to the list of potential targets compiled by the intelligence community. Once the list of applicable targets is identified, the issue becomes deciding what actions to take.

The military operations domain is a "solution rich" environment[6] with numerous alternatives available to satisfy almost every objective. The key then is to find the set of tasks that comes closest to achieving the desired outcomes and provides the best use of available resources.

Objective decomposition is an extremely difficult process to translate into a set of explicit rules for C2 technologies. How does an automated system "decide" which of the potential targets to strike and in what order they should be struck? For example, does one have to eliminate every surface to air missile site to achieve air superiority? Is there an easier, more efficient use of resources that will achieve the same result?

In part, the answer lies in the characteristics of the enemy's integrated air defense system. Is the system centralized, with all decisions made a central location or do local commanders have the authority and inclination to carry out local or regional air defense objectives? It is clear that the knowledge base must include some descriptive characteristics about the adversary if it is to be truly useful in supporting the decision maker. Political, military and technological characteristics all contribute to the selection of a course of action from the available alternatives. Is it possible to construct a set of objective and task templates that match to a set of descriptive characteristics of a potential adversary? By taking the three major groupings listed above, it is possible to adequately describe the potential adversary's political and military doctrine and the support provided by the technological infrastructure. Characteristics cannot be based on doctrine alone. They need to be modified based

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[6] Myers, Karen L, Smith, Stephen F, Hildum, David W, Jarvis, Peter A., de Lacaze, Raymond, "Integrating Planning and Scheduling through Intensity Adaptation", 2001

on observed application of the doctrine in actual operations. The problem in modifying the characteristics based on observations is that we have to then characterize the operation where the observation is made. Location, objectives and opponent all have an influence on military actions. For example, were the military actions taken by Iraq in its war against Iran indicative of the Iraqi response to the allied forces in Desert Storm?

The previous example highlights the second type of characteristics included in the strategy to task decomposition process. The characteristics of friendly forces, along with political limitations imposed by alliance partners, have a definite influence in the selection of alternative courses of action. The capabilities of the individual weapons systems impose limits on the options available to the commander. For example, stealth aircraft supported a rapid air offensive during Desert Storm. At the same time, the political considerations of the allies imposed limits of the options available.

The inclusion of all of the factors that influence the decision process is an extremely complex search process for matching templates that could be used but are not truly tailored for the specific operation. A human decision maker will still make the final choice so the system must provide an interactive environment where the human and computer form a team that works together to reach a solution. The human will provide guidance and direction initially and the system will provide alternative solutions. This concept calls for new visualization tools that allow the human decision maker to see and assess the impact of decisions. The visualization tools need to show the impact of human and machine inputs. Inputs will include decisions such as the selection of one alternative, constraints that limit the freedom of choice, and the characteristics described above that guide the search for solutions.

The result is a complex network of task templates since no single template would satisfy all of the high level objectives. So how does the human decision maker select from among the alternatives? Does the human just go down the list and select one template for each objective? Does this selection process introduce conflicts in the overall operation? Are there overlapping tasks? How does the decision maker influence the course of the operation?

One answer is that the decision maker influences the decomposition process by identifying additional constraints and rules to guide the decision process. The interactive process would begin with the decision maker specifying one or more high level goals for the operation. The system would respond with a set of plausible alternatives. Then, as the decision maker adds new constraints in the form of rules and restrictions the system would respond by paring down the list of suitable alternatives. The decision maker would then select specific templates and the system would present the available complimentary templates to satisfy the specified objectives. Visualization tools are needed to allow the decision maker to see the effects and behaviors induced by complex rule sets. Network analysis tools are one possibility for displaying the interlaced networks of tasks with the tasks selected for prosecution highlighted in some manner. But, what specific tasks will the system display. That's where a logical process for objective and task valuation methodologies.

3.2 Prioritization and Task Scheduling

Once the decomposition process is completed, the issue becomes one of prioritization and scheduling. Automated control technologies often look at prioritization in terms of value. How much value does a specific task contribute toward achieving higher-level goals and objectives? Can that value be defined? What algorithm(s) define a consistent relative valuation among all the tasks that make up a military operation? What part of the task valuation process can be performed by technology and which require human involvement? These issues need to be addressed before full use of automated decision tools can take place in military command and control.

Task and Objective valuation directly influence the performance of automated systems by providing the basis for translating generalized templates into specific tasks. A single task may support multiple objectives and, satisfaction of a single objective may require several tasks. The problem is further complicated when dealing with complex tasks and task networks.

Most decision support applications employ some form of a cost – benefit analysis methodology. Benefits are reflected in the values assigned for accomplishing individual tasks while costs are calculated in terms of wear and tear on the units assigned to complete the task and the risk adjusted cost for each assigned unit. A problem with implementing current decision support technology is that each technology employs a different method to calculate both cost and benefits. This makes integration difficult and results in divergent decisions. The human decision maker if left to decide which technology made the better decision. The divergence also causes assessment problems in that it becomes virtually impossible to measure progress toward achieving objectives when everyone is using a different roadmap.

Tasks derive value from a number of sources. First, a specific task has a certain intrinsic value. This base value is modified by overall objectives selected and the relative priority assigned to each of these high level objectives. But how is the modified value calculated? Do we assign a number of points to each overall objective and then allocate these points to each tasks contributing to satisfying the objective? What is the basis for this allocation? Additionally, individual tasks are related to other tasks and the completion of two tasks is often worth more than the sum of the individual tasks. This synergistic effect often observed during actual operations. For example, the destruction of three electrical substations may cause the collapse of entire power grid. If the grid provided the only source of power to a key, heavily defended command and control node then the decision to attack the power grid provides a low cost (in terms of risk adjustments) alternative to a direct attack against the heavily defended target.

Supporting tasks must also be considered in the task valuation process. If a battalion was tasked with capturing a key communications facility located across a major river then capturing the bridges to support the crossing may be a necessary supporting task. The act of capturing the bridge had a low intrinsic value but the act gains additional value when coupled with the capture of the communications facility. But, would capturing the bridge still have value if the original task could be accomplished using airmobile forces?

The purpose of the above discussion was to highlight the fact that additional research is needed in the area of task valuation methodologies. The task valuation algorithm is complex in that the relationship among all contributing factors has to be included. Without a comprehensive, agreed upon methodology, the recommendations of various automated decision support tools cannot be compared to each other and will be suspect.

A similar problem exists in the cost side of the task decomposition equation. Is a resource (weapon system) valued only in terms of its contribution to the current operation? Should potential value be considered as part of the equation? If so, how is the potential value of a weapon system calculated? Without considering potential value, limited quantity, highly capable weapon systems could be lost on high-risk missions because they did not match up well to the capabilities required for the current operation.

3.3 Selecting Metrics and Performance Assessment

The final area addressed by this paper is performance assessment. It relates to the previous two sections because the assessment process uses the value and cost factors, coupled with the value of specific tasks as part of a decomposed network, as the yardstick used to calculate progress.

DARPA's Agile Control of Military Operations project explored several options for assessing progress toward operational objectives. The simplest methods called for a simple calculation of task value achieved over time. This methodology does offer simplicity but poses several challenging issues. First, the assessment needs to be based on achieved net value to account for the costs incurred. Second, assessment valuation methods that look at total value achieved may neglect efficient options where both cost incurred and value achieved may be relatively low.

The assessment process also requires a simulation capability to assist in predicting the expected values and costs over time. These expected values provide the basis for comparison of actual values. Deviations from the expected values will be normal but the assessment should look at trends in the deviation. The process is similar to the control of manufacturing processes where deviations are allowed as long as they fall within a set range from the optimal value. The key is to recognize emerging trends toward the limit and to take corrective action to reverse the trend.

Performance assessment takes two forms. First, it is important to measure progress toward achieving goals. This is an operational assessment and measures how well the plan is progressing. The second element of performance assessment measures combat performance and looks at costs in terms of losses. The combat assessment process examines how assigned units are performing plan tasks. It seeks to identify variations in lethality for both friendly and enemy systems. The question that needs to be answered is, is the assessment process accurately measuring progress toward achieving military objectives?

Unfortunately, the answer is often no. The missing element in this process is a calculation of how well the planned actions achieving the desired effects. Effects based assessment goes beyond the simple cost-value calculations that often characterize automated control technologies. The original decision to perform a series of actions was based on assumptions concerning the enemy's response. But, were those assumptions correct? Is the strategy working? What are the indicators that actions are achieving the desired effect? How are those indicators described and measured?

The last question posed in the previous paragraph relates directly to the employment of automated detection and measurement tools to support dynamic control of military operations. Sensor technology has advanced to the point that virtually all actions and communications are detected. Decision makers, either human or automated, can be inundated with a flood of information related to all aspects of the battle space. Filtering this mass of information to identify the elements of information that are truly meaningful requires the identification of the critical elements. This identification needs to incorporate specific rules that support the processing of ambiguous and often conflicting inputs. It also means that the task scheduling and resource allocation processes must be able to function in the face of ambiguity and conflict. For example, in the absence of specific evidence, does the system assume that tasks are complete or incomplete? The selection of either alternative leads to a dramatic change in system performance and the conduct of an operation.

4 Conclusion

There is a role for decision support technologies in the command and control environment. The real issue is not technological but one of understanding. How well do the practitioners of military command and control understand the underlying rationale for decision making?

This underlying rationale needs to be captured and incorporated into a new generation of command and control simulations that focus on the distributed decision making processes that constitute command and control. These simulations will allow the military to systematically evaluate the role of various factors in command and control decisions and to assess the impact of inserting new technology into the system. The analysis, supported by these simulation tools will contribute toward managing command and control as a weapon system in the future.