Joint Synthetic Battlespace: Cornerstone for Predictive Battlespace Awareness

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Track: 3 (Modeling and Simulations)

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Abstract

A 1995 vision statement for Air Force Modeling and Simulation highlighted the need for a Joint Synthetic Battlespace (JSB); an environment in which warfighters can train using real-world equipment, while "virtually" immersed in a realistic contingency or wartime environment. The Scientific Advisory Board has recommended the need for military information processes to be more predictive, thus enabling commanders at the strategic, operational and tactical levels to anticipate rather than react: this is referred to as "Predictive Battlespace Awareness (PBA)." This "predictive" capability must link national and military ISR platforms and bring a warfighting focus to the entire C2 enterprise. Although the term "PBA" is widely used, the pervasive cultural change required has not taken root. The problems faced by our decision makers have not changed much over time, namely: inability to accurately predict the course of action of an adversary or the inability to adequately "visualize" the battlespace in order to make better informed decisions. This paper provides a top level view of PBA and explores the utility of a Joint Synthetic Battlespace that would provide the "core" functionality of the PBA. The required information technologies to fully realize a JSB within the total PBA construct will also be discussed.

Introduction

The military commander must be able to live in the future, understanding the impact of decisions made today on the battlespace of tomorrow. The more senior the commander the farther into the future he must be able to see. At all levels, commanders are constantly forming decisions based on their current understanding of the world and their ability to forecast the outcome of actions being considered. This ability is forged through years of training, combat experience and a rigorous selection process. And yet, even experienced tacticians are only able to consider 2 or 3 possible courses of action for all but the simplest situations. Furthermore, commanders often don't have a good "feel" for the sensitivity of their plans to variations or the unintended consequences associated with the expression of their intent.

Czerwinski has argued that: "The function of command is carried out by direction, by plan, or by influence. While not mutually exclusive and often employed in combination, these methods, or archetypes, are dominant.(1) While technological advances have affected these methods incrementally over time, the effect of the Information Age is such that all three methods are for the first time embodied in contending automated information systems developments. Each of these three methods are responses to the pervasive underlying commander's quandary -- uncertainty and insufficient information."[1]

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[1] Czerwinski, Thomas J. "Command and Control at the Crossroads," Parameters, Autumn 1996: 121-132

Czerwinski goes on to describe command by direction as the type of command that was executed when the commander was able to observe the entire battlefield and either attached himself to the element of the force that he believed would be decisive or he would spread his time by moving from unit to unit. Regardless he would exert direct command over some portion of the force.

Command by plan was the invention of Fredrick the Great who tried to plan everything in advance and depended on highly trained troops and strict discipline to carry out the plan as ordered. Again to quote Czerwinski: "The highly centralized command-by-plan formula evolved into the norm for the command of modern military forces. "This has been accompanied by much experimentation and adaptation in doctrine and systems to support the method, and in training, equipping and organizing the force to operate according to plan. However, as with all plan regimes, increased complexity has kept pace with heightened competency. The reason is that command-by-plan inherently fights the disorderly nature of war as much as the adversary. It is a futile quest to will order upon chaos. The contemporary C2 equivalents for this method are the various forms of plan regimes under the broad designation of precision warfare. Foremost among these is the "System of Systems" concept based upon achievement of dominant battlespace awareness, or knowledge[2], and the Air Forces' air campaign methods and supporting systems.

[In the command by influence method], only the outline and minimum goals of an effort are established in advance, effectively influencing all of the forces all of the time. Great reliance is placed on the initiative of subordinates based on local situational awareness, which translates to lowered decision thresholds. It relies on self-contained, joint, or combined arms units capable of semi-autonomous action. All of this activity occurs within the bounds established by the concept of operations derived from the commander's intent."[1]

Regardless of the command method, it is imperative that the commander understand the consequences of his selected course of action. While information technology has improved the commanders "situation awareness" and has afforded the opportunity for flattening of command hierarchies, it has also increased the complexity of the decision making environment. Future concepts for command and control seek to reduce the numbers of personnel assigned to operations centers and to provide better, fused information to the commander allowing him or her to make more rapid decisions and effectively more direct control.

Providing a prediction of what may happen regarding red and gray forces is a necessary ingredient for the Combatant Commander. Predictive Battlespace Awareness encompasses a complex technical issue. It is a very complex cultural issue for the Air Force in that is has to deal with a cultural change, organizational change, architectural change as well as a technology change. This paper only deals with the technology changes required to visualize a PBA environment. A key ingredient to PBA is to provide a simulation capability so the Commander can "visualize" the potential "futures". This simulation capability can take on many forms, but has been "dubbed" the Joint Synthetic Battlespace.

This paper discusses the role the Joint Synthetic Battlespace (JSB) plays in relation to Predictive Battlespace Awareness (PBA). The goal is to develop high-quality "futures" in order for the Commander to make the best possible battle plan given the high-paced battle environment. This

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[2] Adm William A. Owens. "The Emerging System of Systems," Proceedings. May 1995: 35-39.

paper also discussed what technologies would be required to realize a Joint Synthetic Battlespace "holo-deck".

Predictive Battlespace Awareness

There are many definitions of PBA being used throughout the Department of Defense (DOD), but none fully captures the fullness of this concept. Using Intelligence Preparation of the Battlespace (IPB) analysis and effectively employing Intelligence, Surveillance, and Reconnaissance (ISR) systems, the air and space commander may become aware of recent, current, and near term events in his battlespace. However, what is missing is the commander's full participation in a predictive culture that drives the interagency, joint, and Service communities to anticipate the evolution of the global environment, the Area of Responsibility (AOR), and the battlespace far enough in advance to definitively effect the course of events in our favor. Sensing the vast potential of the PBA concept, the AF Chief of Staff directed the Air Force Scientific Advisory Board (SAB) to study *Predictive Battlespace Awareness to Improve Military Effectiveness*.[3]

A fundamental finding from the SAB Summer Study is that "…in today's complex crisis and warfighting environments, deficiencies at the joint, Service, and interagency levels complicate the air and space commander's ability to achieve and maintain this pivotal advantage of predictive awareness. Commanders lack persistent intelligence, surveillance, and reconnaissance (ISR) assets and access to pertinent non-ISR information sources. They lack adequate command and control of the ISR assets at their disposal. They lack sensors that can discern the kinds of subtle phenomena necessary to build a complete picture of the battlespace. They lack immediate access to relevant, fused, timely information. They lack the decision-making, management, and prediction tools required to create definitive effects in the battlespace…."[4] This leads to a redefinition of exactly what is Predictive Battlespace Awareness.

The Scientific Advisory Board (SAB) defines Predictive Battlespace Awareness (PBA) [5]as: "PBA is the state of mind that is achieved and maintained by a commander through active participation in the "predictive process." Furthermore, the SAB defines "Pre-conflict PBA" as the commander's knowledge of the possible future activities and adversaries in his area of responsibility along with their worldviews, political tactical approaches, and other factors that will be relevant in the event of conflict. Using Pre-conflict PBA, the commander anticipates when and where action will occur and then focuses on blue, red, and gray interactions in that area, often with the intent of avoiding conflict altogether. "Crisis/Conflict PBA" is the commander's knowledge of these pre-conflict factors and his anticipation of how these factors will evolve, sharpened and confirmed by timely sensing.

[3] SAB-TR-02-01, "Predictive Battlespace Awareness to Improve Military Effectiveness," August 2002.
[4] SAB-TR-02-01, "Predictive Battlespace Awareness to Improve Military Effectiveness," August 2002, page 4
[5] SAB-TR-02-01, "Predictive Battlespace Awareness to Improve Military Effectiveness," August 2002, page 3.

PBA differs from Intelligence Preparation of the Battlespace (IPB) in a number of fundamental ways. Table 1 provides a summary that was taken from the SAB PBA Summer Study[6].

Table 1: IPB vs. PBA

IPB	PBA
Intel-centric	Commander-centric
Product-centric	Process-centric
Structured, iterative process	Dynamic Process
Focuses on red as an independent actor	Emphasizes red-blue-gray interaction and interdependencies
Describes adversary's courses of action	Emphasizes commander's anticipation and pre-emption of the adversary through decisive effects
Focuses on courses of action initiated after inception of conflict/crisis	Enables the commander to shape the pre-post-conflict environment to his advantage; reduces uncertainty during conflict/crisis
Generally delimited by specific geographical boundaries (operational and/or tactical levels)	Provides continuity of awareness from the strategic to the tactical level of operation
Focuses on target identification / definition	Focuses on commander's decisions to produce decisive effects in the battlespace
Stovepiped processes and information-flow	Horizontally, vertically integrated processes; ubiquitous information through the publish-subscribe-broker information architecture

In previous OSD/C3I work, they have developed a conceptual model for Command and Control as shown in Figure 1. Previously, whenever command and control was shown, invariably ground, air and space nodes with interconnected links were shown as the "Command and Control Architecture". This is not a true representation of Command and Control. Command and Control is simply "command" and "control". It is a Commander's responsibility to propagate a military engagement to a satisfactory endpoint for the United States. The work OSD/C3I has done is to capture the Commander's process into a conceptual model that deals with the Command and Control aspect of a military engagement. This is a necessary step in visualizing exactly what is Command and Control from a Commander's perspective.

[6] SAB-TR-02-01, "Predictive Battlespace Awareness to Improve Military Effectiveness," August 2002.

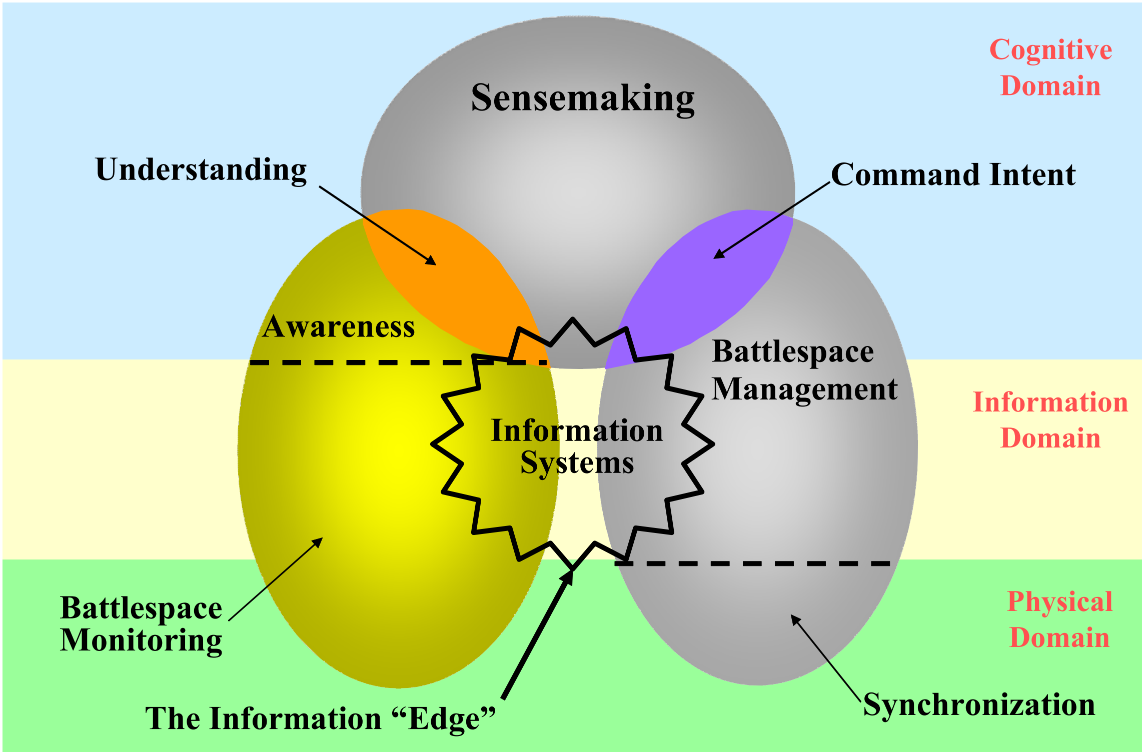

Figure 1: C2 Conceptual Model

Using Figure 1 as a foundation, Figure 2 provides a conceptual view of what is PBA[7]. The key end-point for PBA is developing "futures" so the Commander can get a comprehensive view of what might happen given a set of Courses of Action (COAs) that takes into account Red, Gray and Blue capabilities.

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[7] Concept developed from OSD/C3I framework at an internal AFRL/IF PBA workshop. Special thanks go to Todd Humiston and Mark Pronobis for their insightful suggestions.

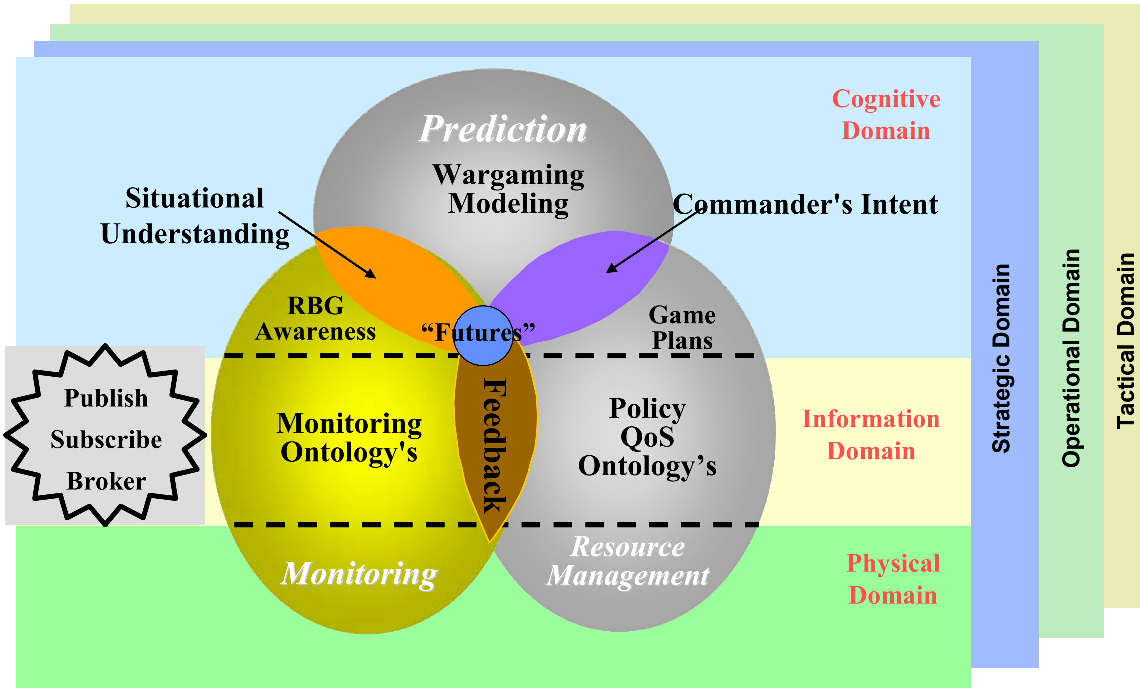

Figure 2: Conceptual View of PBA

If you look at PBA as the overarching process that occurs at all levels of command (Strategic, Operational and Tactical), then IPB can be thought of as the critical front-end set of activities that must be accomplished to ensure the commander has the current intelligence information regarding the red and gray forces.

Joint Synthetic Battlespace

The concept for the Joint Synthetic Battlespace was identified in a publication released in June 1995 by the Air Force chief of staff, Gen. Ronald Fogleman, and the Secretary of the Air Force, Dr. Shelia Widnall titled "A New Vector: Air Force Modeling and Simulation". The objective was to create an integrated modeling and simulation environment to support analysis, training and acquisition. This environment would be one in which warfighters can train using real-world equipment, while "virtually" immersed in a realistic contingency or wartime environment. New ideas for weapons or changes in doctrine could also be evaluated in this virtual war. The emphasis is on providing an accurate and comprehensive synthetic environment that provides consistent correlated data.

The increasing pace of decision making coupled with the reduction in personnel lends to the belief that the commander will need improved tools to command. One of them is operationally focused simulation in the context of a Joint Synthetic Battlespace. Operationally focused simulation extends the concepts of the Joint Synthetic Battle Space to include the blending of real and synthetic battlespace data. Rather than virtual reality we are referring to augmented reality. The goal is to allow the commander to improve her insight to unfolding situations.

In several seminal papers on the subject, Surdu, Hill, and Pooch identify a subject area that they refer to as "synchronized simulations in planning systems" and sometimes also call "operationally-focused simulation"[8,9]. The basic theme of the Hill and Surdu research is simulation during actual operations for the purposes of assisting the planner. In other words, they describe systems in which you simulate the future outcomes of current real world operations. From moment to moment, one is moving forward from ground truth in excursions towards a theoretical future outcome. This system offers the potential to the commander to see and understand the effects of current decisions on possible future outcomes and to examine the decision landscape identifying where it's critical to "get it right". It also offers the potential for identifying gaps in knowledge and the value of gathering additional information.

There exists a large volume of prior art on the subject of strategic, operational and tactical conflict simulation; indeed, this is one of the oldest subjects of computer science. Even so there are still major needs in the DoD simulation community. Human models of behavior, effects-based modeling and simulation, distributed command and control simulation, even simulation for the purposes of execution planning and re-planning – these are all identified shortfalls in the modern simulation arsenal, and have therefore been the subject of much recent research.

In addition to these prior areas, there exists at least one major shortfall in the simulation community that is well identified, but is otherwise sparsely funded, and is the subject of only very small amounts of prior work. This is the subject of *real-world-synchronized simulation* – simulations that simulate, but are intended to take their ground truth from a real world operation, and project a future.

This is a difficult problem area. In order to simulate anything during operations, one must assume away lengthy and complicated simulation setup. There's simply no time for it. And realistically, the staff that is dedicated to gaming during peace is often reassigned directly to operations during a real conflict. This means that simulation operators are generally unavailable during actual crises. Such a simulation therefore needs to set itself up automatically, with little-to-zero intercession from the operator. The simulation environment will have to be created from our current and past knowledge available in operational databases. Terrain from DTED, features from DFAD, red capabilities from MIDB, current vehicle movement tracks from TMDB, Blue planned activity from AODB or OPORDs, munitions availability from CAS-B, weather, and others will be used to place objects in this world. The point here is that we should not have to act on specialized simulation specific data but on the data that is in operational use.

Furthermore, consider: operations are ongoing. They proceed forward in time at a pace beyond one's control, and are constantly receiving an influx of new information. Perceived ground truth is altered. Facts that were thought to be true are changed. At any given moment, the entire operational awareness of the scenario is subject to revision. In such a setting, it's simply not possible for a simulation to proceed forward from a one-time-only setup and to thereafter predict the future in small steps. Any simulation conjoined with a live operation must be subject to constant revision. In fact, any such simulation should likely be written to understand that situational data is uncertain.

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8 "Synchronized Simulations in Planning", Hill, J. Surdo, J., et al. Advanced Simulation Technologies Conference: Military, Government, and Aerospace Simulation Symposium, Seattle, WA., 22-26 April 2001, pp. 76-81
9 "Simulation Technologies in the Mission Operational Environment", Surdo, J., Pooch, U. SIMULATION 74:3, 2000,138-161

This combination of rapid setup and self-revising behavior implies intelligent integration with real world databases. The setup of any simulation should be *implied* by the current operational state. Command-control of the simulation entities should at least in part occur through *standard planning tools*. Various authoritative reporting sources should be scanned to correct the current simulation state, implying *selective rollback* of some simulation events and outcomes in the event that real world sources report differing results than the model predicts in its current and near-future simulation state.[10]

JSB and PBA Technology Challenges

There are a host of technologies required in order to develop a comprehensive "operationally focused simulation" capability as a part of the overall JSB architecture in support of PBA. Here are some of the major ones:

- **Organizational behavioral modeling**. Development of concepts and tools which have the ability to predict and assess what will happen based on organizational information/knowledge gathered. The predictive modeling needs to take into account, doctrine, law, culture aspects of the adversary, past experience/knowledge of the adversary, coalition/ally response to any action taken or not taken, etc. The goal is to be able to model an adversarial intent and must include non-conventional warfare as well as conventional.

- **Faster than real-time execution**. There are a variety of techniques being pursued to achieve high fidelity data from simulations in faster than real-time. They include:
    - Multi-Resolution Modeling
    - Concurrent Simulation
    - Model Abstraction

- **Data Mining**. Provide rapid search of very large databases (petabytes) to identify patterns, trends and anomalies that can be rapidly exploited. Provides the ability to correlate "seemingly irrelevant" information into a coherent "picture". This requires upper level fusion techniques (levels 3 and 4) along with information understanding.

- **Distributed Processing/ Distributed Simulation.** The melding of current real information provided by the Joint Battlespace Infosphere with simulated data provided by High Level Architecture (HLA).

Regarding Predictive Battlespace Awareness, the following are critical challenges along with associated technologies[11]:

- **Direct, with precision, the location, identification/monitoring of all ground, air and space objects and events.** Achieving constant observation of stationary and moving objects under the ground, on the ground, in the air and orbiting in space is always

[10] M.J. Brown, "Operationally Focused Simulation" AFRL contract F30602-02-C-0233.
[11] Material taken from the Command and Control Long Term Challenges taxonomy accomplished for SAF/AQ in 2001.

important to the battlespace commander. This also includes activities of military significance that would provide the earliest possible warning. Relevant technologies are: polymorphic auto-configurable hardware/software and intelligent sensors.

- **Direct the collection of physical environmental and social/political/economic information.** An important element in any military planning and execution activity is the complete understanding of the environment; to include: weather, terrain, etc. Potential adversarial culture, religion and experiences must be assessed in order to develop a suitable military plan that will achieve national objectives with minimal loss of life. Relevant technologies are: knowledge discovery and reasoning; multi-domain information fusion and normalcy reasoning.

- **Direct the instantaneous detection of any red, blue, gray operational deviations.** Over time, activity patterns can be discovered. Airlines fly between cities on a schedule. Traffic flows have peak congestion at well recognized times. Foreign governments schedule military exercises on a regular basis. The US is surrounded by global activities that follow established and predictable patterns. These activities can be captured and used to ascertain normal government and military activity. Activities outside these norms serve as a red flag to warn our warfighters of potential adversarial actions. Pattern identification can be accomplished automatically, thus saving manpower for more important assess, planning and execute functions. Relevant technologies are: automated identification of centers of gravity and language translation.

- **Full spectrum aerospace vigilance.** Assessing the nature and impact of any and all critical events (e.g., Blue, Red and/or Gray force movements) whether originating on earth or in space is important to the battlespace commander. The goal is to determine the military implications of fused intelligence indicators, all source information, and orders of battle of Blue, Red and Gray forces. One must take into account all relative ROE's, treaties, and agreements and have the capability to assess termination options, conditions, and proposals. Relevant technologies are: optimization of C4ISR resource allocation under uncertainty; intelligent dynamic intelligent agents; machine learning; and, information assurance.

- **Predictive and precise battlespace understanding.** The decision maker must have the capability for continuous and seamless intelligence preparation of the battlespace that accurately determines and predicts enemy order of battle, enemy capability and vulnerability with intentions for contingencies in progress and post-attack. The battlespace commander also needs to assess adversary's ability and intent to use weapons of mass destruction and information warfare. Continuous predictive battlespace awareness is also the ability to identify and target Time-Critical-Targets in theatre in real-time and the ability to predict adversary response to any attack. The battle staff must have the rapid capability to perform accurate assessments of battle damage and effect on the adversary. Relevant technologies are: high level fusion (levels 3-4); knowledge pedigree; deep extraction; and adaptive languages.

- **Battlespace wide "Effects-Based-Operations".** Effects-based operations (EBO) are those set of processes, supported by tools and done by people in organizational settings, that focus's on planning, executing and assessing military activities for the effects they produce rather than the targets or even objectives they deal with. Battlespace wide "EBO" complements rather than replaces target-based or objectives-based approaches (such as strategy-to-tasks). Battlespace wide "EBO" is not platform specific and applies across the entire range of military missions from humanitarian relief operations (HUMRO), peace making or enforcement operations, or conventional war. It applies whether lethal or non-lethal, kinetic or potential force is used. Relevant technologies are: emergent behaviors of complex adaptive systems; real-time updating of simulations; knowledge pedigree; and, high level fusion algorithms.

- **Brilliant Air and Space Operations.** Ultimately, this will provide the Air and Space Operations Center of the future with increased capability with fewer personnel placed in "harms way". Provides "quality level information" to the decision maker versus reviewing mountains of data/information which can be achieved through automation. The key to brilliant air and space operations is the ability to make no risk decisions, in time to control the pace and phasing of the conflict on a global scale if necessary. Relevant technologies are: cognitive reasoning; advanced human system and cognitive skills; self-learning knowledge extraction; and, self-generating knowledge databases.

- **Dynamic Virtual Checkmating.** Deals with the concept of a chess game applied to tomorrows conflicts. The idea of being able to run a very detailed "Game" to determine the best course of action from the Blue side and an analyses of the Red and Gray possible reactions would be the resultant product. Because the models would be of such high fidelity and the processing of the simulation would be so quick the commander and his/her staff will be able to effectively make the best cost/benefit decision based on intent within a short period of time. Relevant technologies are: next generation (quantum) computing to solve n-p hard optimization problems; adaptive simulation frameworks; and, pattern-based "behavior" modeling and simulations of the decision maker.

- **Autonomous Execution with tethered control.** Refers to the automatic control of selected low level functions. For example it is possible to envision a future where, for the most part, air traffic control will be automated. This doesn't imply that there is no possibility of human supervision or intervention (in the same sense that a traffic light can be overridden by a traffic cop). Automation of these systems would allow for far greater efficiencies at low risk. One of the tenets of air power is the use of centralized control and decentralized execution. During the execution phase distributed control will be necessary. The challenge will be to implement it in such a way as to preserve the benefits of centralization while gaining the speed and flexibility associated with decentralization. Relevant technologies are: large-scale cooperative path planning; decision and stochastic game theory; predictive/cooperative control; and, intelligent communications.

- **Adaptive, continuous rolling execution at all levels with both precision and speed.** This is the ability to concurrently execute and plan in a continuous cycle. This continuous plan needs to address the need for forecasting future actions and initiating the execution in some cases even before the detailed planning is complete. An important component is the dynamic re-tasking of assets with minimum perturbation to the overall plan. Relevant technologies are: dynamic modeling; real-time simulations; perturbation theory; autonomous rapid coordination; and, large-scale combinatorial optimization.

- **Global Warrior Presence.** The ability to project the presence anywhere on the globe or in space instantaneously. Projection of presence may be through collaboration or sharing of information and knowledge, or through immersive, virtual presence. Support the execution of time-critical actions by rule-based cyber delegates. Relevant technologies are: smart interfaces; data/knowledge fusion, translation and mediation; virtual command centers; virtual reality; and immersive/multi-sensory interfaces.

- **Air and Space Information Exchange.** The ability to communicate, network, move, and protect information regardless of constraints of distance or conditions, including the adversary's attempts to deny these services. Relevant technologies are: enterprise management; synthetic rehearsal/training; and, self-forming annealing networks.

- **Brilliant Workflow/Decision Support.** The ability to capture and embrace the C2 enterprise in an agile, intelligent C2 decision infrastructure. Additionally, this allows the battlespace commander to seamlessly integrate continuous planning, execution & assessment at all levels of command. Relevant technologies are: adversarial culture modeling; adaptation/context reasoning; and, decision/workflow capture.

- **Knowledge Sharing.** The ability to create a shared understanding of the battlespace to support the process of decision-making and execution at all levels of command. This requires the ability to capture the intent of the participants, fuse information in terms of its context, and disseminate the shared view regardless of language, terminology, or data formats. Relevant technologies are: data/knowledge fusion, translation and mediation; adaptation/context reasoning; and, smart interfaces.

Summary

The military commander must be able to live in the future, understanding the impact of decisions made today on the battlespace of tomorrow. At all levels, commanders are constantly forming decisions based on their current understanding of the world and their ability to forecast the outcome of actions being considered. This ability is forged through years of training and combat experience. And yet, even experienced tacticians are only able to consider 2 or 3 possible courses of action for all but the simplest situations. Furthermore, commanders often don't have a good "feel" for the sensitivity of their plans to variations or the unintended consequences associated with the expression of their intent.

Predictive Battlespace Awareness, like Effects-Based Operations, has the potential to fundamentally transform the way the Air Force plans, prepares, trains, and fights. Immersed in a culture of prediction, air and space commanders will be able create preemptive, decisive, full-dimensional effects throughout the battlespace — anywhere, anytime.[12]

[12] SAB-TR-02-01, "Predictive Battlespace Awareness to Improve Military Effectiveness," August 2002

The Joint Synthetic Battlespace is the key to a successful Predictive Battlespace Awareness implementation.
The increasing pace of decision making lends to the belief that the commander will need improved tools to command. One of them is operationally focused simulation – Joint Synthetic Battlespace. This operationally focused simulation offers the potential of providing an augmented reality for the commander improving his insight to unfolding situations.

The key to success is the effective merging of JSB into PBA to provide a Commander with decision-quality "futures" in order for a successful conclusion of the battlespace environment is achieved.

Bibliography

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