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Beyond Situation Awareness: The Battlespace of the Future

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The power of information as a "force multiplier" has been a central theme of command and control (C2) for many years. That theme has evolved to a major emphasis in reshaping our view of the future battlespace, as expressed in Joint Vision 2010 (JV2010) and in prior efforts, such as "C4I for the Warrior" and the Navy Copernicus initiative. In all of the discussions related to "information superiority" situation awareness has been a major element. Situation awareness takes the form of the common operational picture (COP), the consistent tactical picture (CTP), the single integrated air picture (SIAP), and numerous other representations of the battlespace situation. It is viewed as a key to battlespace dominance; the leveraging of superior knowledge of the battlespace to gain operational advantage over the enemy.

While situation awareness is obviously vital for C2 and execution of combat missions, it is not the real key to success in the information-intensive battlespace of the 21st Century. It is only an enabler. We need situation awareness to be able to achieve information superiority, but simple awareness is not enough. We need to be able to use our superior knowledge of the battlespace to make decisions and take actions that allow us to dominate the battlespace.

Knowledge itself, without an ability to understand and act upon that knowledge, is not very useful.

Situation awareness is useful only if we can act upon that knowledge, first by understanding what it means and second by appreciating it in terms of our own objectives and constraints. One of the greatest challenges facing the operators and technology providers is to match our increasing capability to gather, process, and display situation awareness information with a corresponding increase in our ability to use that information.

<u>The Mixed Blessing of Expanded Access to Battlespace Information</u>

Conventional wisdom is that the more we know, the better we can decide and act. In fact, that may not be the case unless we are careful to gather, integrate, and present information in a way that supports the decision maker's cognitive processes. We are now at a point where the addition of more information may actually be counterproductive. Additional information brings with it the potential for additional ambiguities and the need for the users to service a greater number and types of information inputs. The result may actually compound the "fog of war" with a new "glare of war" or information overload.

Increased availability of situation information may also be counterproductive with respect to time critical decision making. When the decision makers expect information to be sparse, they tend to rely on judgment and experience to fill the voids. When information is massive and confusing, decision makers may often delay taking action until additional information can be gathered to fill voids or resolve ambiguities. They may reorient their decision making process from judgment based on experience to reliance on detailed analysis based on hard data. The result can be "analysis paralysis," leading to a delay of the decision until it is too late.

Information that confuses or confounds the decision maker can disrupt an "otherwise good enough" judgmental decision process and thereby degrade operational effectiveness.

We certainly want increased situation awareness, but we also want the means to interpret this increased base of knowledge so that it helps rather than hinders the decision making processes. This is where we move to the next level of information superiority: understanding and appreciating the battlespace situation. This is where we have an opportunity to make a major improvement in warfighting effectiveness now that we have the means to collect, integrate, and disseminate a vast amount of information in the battlespace.

Understanding the Situation

"I don't understand everything I know."

This statement illustrates the difference between awareness and knowledge and the next step in being able to use that knowledge. Understanding requires that we correlate our knowledge or awareness with a contextual model. The contextual model includes two major components. One is the physical world model, and the other is the operational context model.

The physical world model is simply the model that differentiates aircraft from automobiles and that imposes rules such as time ordering of events, causality, and limits on location and movement. If we detect data from an entity in the air, the physical world model tells us that it is an air vehicle and not a ground vehicle. If we detect movement at Mach 1, the physical model tells us that it is probably not a helicopter.

The operational context model allows the observed information to be viewed within a broader set of entities and events in the current situation. For example, information about a vehicle moving along a road can have different meanings, depending on the operational context. If the context is a morning rush hour, the vehicle is simply one of many making its way from home to work. If the context is a land battle, the vehicle may be part of a friendly, enemy, or neutral movement through the battlespace. Also, the operational context model includes information on organizations in the battlespace, such as enemy order of battle. This allows the observed vehicle to be perceived as part of a specific enemy organization.

Understanding requires that we match our awareness with context so that meaning can be determined. This generally requires integration of numerous elements of the situation picture to establish patterns that match expected behaviors. If we have too little information, we are presented with too many possible alternatives, hence the "fog of war." If we have too much information and insufficient context or judgment to recognize the patterns, we encounter the "glare of war". If we have sufficient information and appropriate pattern "templates", then we begin to use enhanced situation awareness to our advantage. The "pattern templates" can be based on human judgment and experience or on automated rule sets or, more likely, on a combination of the two.

Pattern interpretation of this type can be thought of in terms of multiple alternatives, or hypotheses, regarding the situation, each of which can be verified or negated by recognizing critical discriminants. This is the basis for use of multi-hypothesis trackers (MHTs) to aid understanding.

MHT technology has been used extensively for monitoring the environment to detect and track stealthy targets such as submarines. That application supports situation knowledge rather than understanding, since it tends to build a picture of individual entities rather than multi-entity patterns.

More recently, MHTs and more sophisticated diagnostic tools such as Bayesian nets and "fuzzy logic" are being applied to the overall situation picture to detect patterns that may indicate significant battlespace entities and events. The situation awareness picture is thought of as a multi-dimensional state that can be defined and evaluated with mathematically sound logic and consistency. The result is an ability to interpret battlespace knowledge in terms of likely alternative meanings, each of which can be characterized by a level of confidence. The result also identifies key observables that can help distinguish between the different alternatives. These tools allow the users to view situation awareness information not simply as a collection of independent entities and events but more as an integrated pattern of information that has meaning in terms of current and likely actions of friends and adversaries. This takes us one step forward from situation awareness to being able to understand the situation and make appropriate decisions.

Understanding has several dimensions. First of all, we need to recognize what the patterns mean as noted previously. Second, we need to recognize how much of our understanding is based on deterministic "facts" versus probabilistic estimates. We also need to recognize where we have made assumptions to fill voids in the observations. We need to keep track of those assumptions and of observations that seem to be outliers but that may really imply "unknown unknowns" waiting in the wings. The main point is that our understanding is never more than a probabilistic inference. It can be very reliable, but it cannot be absolute, since we can only interpret what we measure, and measurements are never perfect. We never really know "ground truth".

Surprises occur when we draw conclusions and take actions without remembering that some of our "awareness" was actually based on assumption and not direct observation. Other surprises occur when we encounter the unknown unknowns.

One of the most difficult areas for S&T is the application of mathematical formalism to interpretation of situation awareness information. We need tools that help us deal with the massive information, and to keep track of the underlying statistical factors, uncertainties, gaps, and assumptions. Unfortunately, the "state vector" that describes the battlespace situation is not as simple or intuitively obvious as the "state vector" that describes an air track or a ship or submarine track. Consequently, the mathematical formalism will not be as simple or intuitive as rate-aided linear track extrapolation. The mathematical formalism for dealing with this problem remains to be developed.

Mathematical consistency and discipline are needed to deal with the combined "fog of war" and "glare of war" in the information-intensive battlespace.

As situation awareness information becomes more complete, more complex, and more diverse, we require greater ability to provide credible interpretations to aid the users in understanding the information. Unfortunately, it is exactly the increase in power for assembling the situation awareness picture that increases our problems in dealing with this picture. As we add information, we increase the dimensionality of the situation "state space" and we increase the demands on the mathematical tools to deal with this "state space". In the end, we may compound the decision maker's problem by adding information.

Without the tools to handle increased size and complexity of the situation awareness picture, we may sometimes find that less information is better than more.

Perception as the Basis for Understanding

Understanding and subsequent decision making is based on the user's perception of the situation. Perception is the mental picture of the situation that he or she develops based on the presented information. One way to think about perception is in terms of a "perception map" as shown in Figure 1.

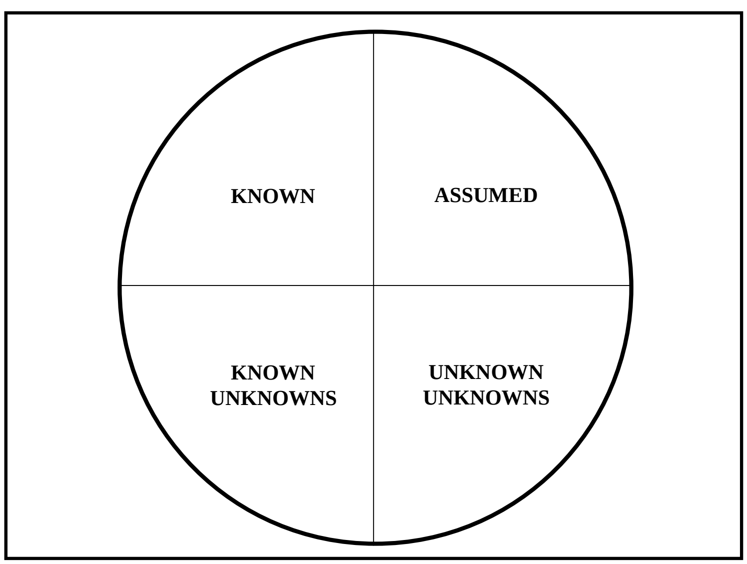

Figure 1. Perception Map

Our "awareness" of the situation contains three contributing elements: known information, assumed information, and known unknowns. A fourth element, unknown unknowns, is present but not obvious to the user and can introduce opportunity for confusion over the meaning of known or assumed information. It can also cause surprises when events occur that should not have been possible according to the user's perception of the situation.

In forming our perception we will always be guided to some extent by predisposition to assume something about the situation. We never enter a situation without some sort of preconceived notion of what we expect to find, and if we are not careful, that can distort our perception. It can produce a "filter" that causes us to weigh certain information more than others, based on what we expect to see.

A critical part of the perception is the "self-deception" that we will generally encounter at the early stages, before real world information forces us to move from preconceived notions to hard realities.

The statistical nature of situation information and the degree of confidence, or willingness to accept information, causes other problems in forming a valid perception of the situation. The perception map shown in Figure 1 is not really a true representation of how we view the situation. The problem is actually much more complex, since each sector of the map must be further subdivided according to the degree of confidence with which the information is "known" or the assumptions are made. The known unknowns must also be subdivided according to the importance of the knowledge gap and the need to make assumptions. In many cases, an information element in the assumed part of the map will be connected explicitly to a corresponding element in the know unknown area. The user's perception of the situation is consequently based on a potentially complex set of relationships among many information elements at various stages of definition and confidence. This is illustrated in Figure 2.

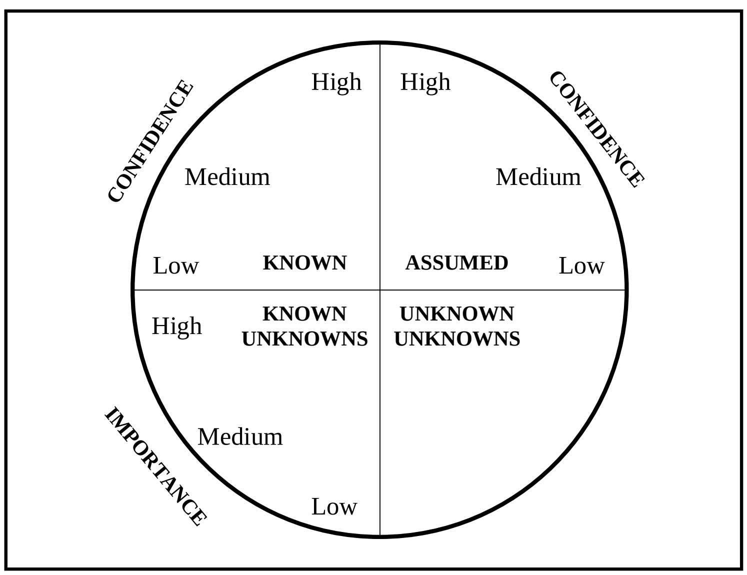

Figure 2. The Perception Map With Confidence and Importance Metrics

Situation awareness provides the information elements, but it does not fully define the relationships or manage the perception or the level of confidence in the perception. Once again, the user needs tools to support his or her understanding and management of perception based on observed, inferred, and assumed information. In the real world, our perception may in fact be built on a "house of cards." One false assumption, or one critical unknown unknown can cause the entire perception to be faulty. This is a well recognized basis for deception tactics. Show the enemy something that he expects and is willing to perceive to be correct, and you can then manipulate his decision process.

Building perception from situation awareness information must always consider the potential for deception, either by one's own preconceptions or by an adversary's deception tactics.

Decision makers move from awareness to perception and then to understanding as they progress through the process leading to decisions and actions. At each stage, the information that is used becomes more abstract, more highly integrated and processed, more decoupled from the basic observations that produced situation awareness in the first place. Think of this as moving from directly observed information to indirectly derived information. The power in this movement is that it provides the integration and patterns that allow understanding. The danger is that it also obscures the probabilistic factors, gaps, and other deficiencies that were part of the battlespace knowledge in the first place.

Decision makers generally use information that could be thought of as "rich metadata" rather than actual situation data. Metadata is information about information. The table of contents of a book is metadata about the contents of the book. The index to the book is also metadata about the book, but it contains more information than the table of contents; it is somewhat "richer" metadata. Similarly, an icon on a map display may represent a military platform or unit. This icon tells us that the database contains information about that platform or unit. It also gives some summary information about that entity, such as its location and movement and its classification or identity. The icon is actually rich metadata concerning the tactical situation database. This is the kind of information that is really used by the decision makers. They use highly aggregated, integrated, fused information that represents a potentially large set of data elements in the situation database. This information may be removed by several stages of processing from the actual observations, so the decision makers generally "take it on faith" that the processing has been correct and that the presented "rich metadata" is an actual representation of the situation. Clearly, this is a great leap of faith, especially when conflicting or ambiguous information appears in the display, and the decision maker may need to be able to ask the system for source data that supports the presentation.

In dealing with derived information or "rich metadata" the user will often need to be able to look at details that underlie the presented information.

It is probably impossible, or at least impractical, to expect the human decision makers to keep track of the source data and all of the statistical measures and to translate them to a statistical interpretation of meaning at the level of situation understanding. This is where automated tools can be very helpful. Computers do several things very well and others not so well. Computers do not "think" and they are far less adaptive than humans at recognizing patterns that differ somewhat from what they were "trained" to seek. However, they are excellent "book keepers." They will not "forget" an assumption when that assumption is registered in the database and they will not forget the rationale for specific semantic linkages among data elements. They are also extremely reliable at maintaining mathematical precision and logic in everything that they do, and they are not predisposed to make judgments other than those that are explicitly entered into their programs. Consequently, automated tools should be a good complement to the human decision maker as the process moves from direct observation of the environment, to integration and interpretation of information, and then to inference and understanding. As the human decision makers move through this process, the automation can keep track of the statistical nature of the results and can continually monitor the source data to advise on changes needed in the interpretation or on changes in confidence levels. The class of intelligent agents known as "automated sentinels" are especially useful in this regard.

Automated tools provide objective, consistent logic that complements human judgment and inference.

Another powerful use of automation is to provide "drilldown" capability. Drilldown is the ability to query the system to look at source data underlying the derived information in the perception map. Decision makers often find that they need to step back from their current interpretation of the situation and ask for a critical piece of information that was used to establish the current perception. Drilldown can be in a form as simple as requesting the specific data element or it can be a more complex process in which the user asks "why" and receives a report on the logic trail that led from one or more observations to a complex conclusion. The simple form is easy to implement. The more complex form generally requires a class of automation referred to as artificial intelligence (AI) or expert systems or rule-based systems.

Automation can support the user's need to identify and appraise critical pieces of source data that underlie the processed situation awareness information display.

Perception management is absolutely essential as we move toward ever greater degrees of situation knowledge. The decision maker needs to be confident that he or she understands the implications of unknowns, uncertainties, and assumptions while being unburdened from the tedious tracking of each bit of data. The humans need to be free to apply human judgment and experience while the computers can track the details and provide cues, alerts, and advisories.

<u>Developing a Military Appreciation</u>

"Now that I understand the situation and recognize potential uncertainties and implications, what should I do about it?"

The answer to this question is the military appreciation and the basis for the decision and action.

Military appreciation results from a correlation of situation understanding with other information such as operational objectives, rules of engagement, own force capabilities, enemy capabilities, and likely enemy intents. We understand what the situation is or seems to be; we understand what we want to achieve and what the ground rules are for our actions; and we understand to some degree what the enemy can do or is likely to want to do. By combining all this understanding we arrive at a course of action to satisfy the objectives and constraints.

The key to information superiority is really an ability to develop a military appreciation and to act on that appreciation in a timely and effective way.

The complexity in the process from awareness to understanding is compounded when we move to a higher level of reasoning demanded for appreciation of the situation. Reasoning must now contend not only with context-based interpretation of information. It must also contend with tradeoff among objectives, capabilities, priorities, and constraints, and it must include adversarial reasoning since the enemy is likely to respond to anything that we do. Our appreciation of the situation must take all these factors into account.

When the situation is well understood and time permits us to develop and analyze alternative courses of action, the problem can be handled by human staffs. We develop the Operation Plan (OPLAN), Operation Orders (OPORDERS), and so forth. The real problems occur when we do not have weeks or months or years to wade through the planning process and when we need to respond quickly to a current situation or when the situation is so complex and confusing that our analytical processes cannot contend with all the potential alternatives. This is where we rely upon our automated systems to assist in developing an understanding of the situation an appreciation of what can be done and an appraisal of the alternative courses of action for both friendly and enemy forces.

The class of automated decision support tools that we would use at this stage are at the leading edge of advanced information technology. We often refer to them as AI tools since they attempt to mimic human reasoning processes. They are not really intelligent – computers do not really think – but they do embody logical processes that are patterned after human problem solving processes. The leap of faith required to accept that an AI tool can actually be trusted to be as perceptive and competent as a Napoleon or a Caesar is too great for any of us to accept at this time. However, as an adjunct to the human decision maker, AI is probably not a bad idea. If the computer's "appreciation" of situation, objectives, constraints, and alternatives differs significantly from the human decision maker's, then the decision maker at least has an indication that something needs to be looked at more closely. If there is general agreement, then that provides a cross-check and identification of the few areas of disagreement that may need to be reviewed.

Appreciation for a complex situation will probably require a mix of human reasoning and computer aided reasoning to provide judgment and experience, complemented by disciplined and logical tracking and consideration of all available information.

<u>Deciding and Acting Upon the Situation Information</u>

Decisions and actions are motivated in three different ways: by process or procedure, by necessity, or by opportunity.

Process-driven decisions are ones where the decision or action is provided according to a schedule. For example, the daily briefing to the commander is a process-driven activity. The Air Tasking Order is another example of a process-driven decision. The main feature of this type of decision or action is that it is not matched to the flow of the battle. Process-driven decisions and actions will always be important at the strategic and operational levels of command, but the tactical level decision-drivers are much more closely aligned with the battlespace situation in near real time.

Need-driven decisions and actions are responses taken to situation changes that demand timely response. For example, an incoming missile needs to be countered; an unexpected enemy attack needs to be repelled; and so forth. Need-driven decisions are reactive and often must be executed quickly.

Opportunity-driven decisions provide an ability to exploit an advantage that is presented either by an enemy mistake or simply by a lucky turn of events. This is one of the keys to success in the battle. If we can recognize the opportunities and make the decision quickly enough to take advantage of them, we can use information superiority to maximum effect.

Need-driven decisions are reactive, and opportunity-driven decisions are proactive. Successful combination of these two capabilities is the key to success in the information-intensive battlespace.

We have two principal ways to incorporate the reactive and proactive actions into the battle plan. One way is to provide for them within the plan. Immediate (on-call) close air support is an example of this. The other way is to provide a means to “replan” or to “repair” the plan. Replanning involves “backing up” to some point in the time-sequence set of planned actions and then reformulating the entire plan from that point onward. Plan “repair” implies taking a small part of the plan, a small “bubble” of interrelated actions, and modifying that part without impacting the rest of the plan. Plan repair is more appropriate for near real time reactive and proactive adjustments, but it also requires very good ability to understand and manage the interactions among affected elements in the plan and other parts of the plan.

<u>Distributed Self-Synchronization</u>

The full impact of information superiority will come through increased speed and precision of command coupled with increased ability of the force to act coherently, with execution decisions pushed as far down the chain of command as possible. Since the mid-20^{th} Century the objective has been “centralized command and decentralized execution.” A decentralized decision-action process can be achieved if certain enabling criteria are satisfied:

a. consistent, shared perception of the situation;
b. consistent, shared processes for understanding the situation;
c. common appreciation of the situation;
d. common doctrine and techniques, tactics, and procedures for taking action;
e. common training to ensure consistent responses across the force.

When these criteria are satisfied, it becomes possible to execute under a commonly understood action plan even when the distributed elements of the force do not receive specific tasking. This degree of coherence across the force is a form of self-synchronization.

An important element in achieving self-synchronization is training and tactics, techniques, and procedures (TTPs) that allow each element of the force to “know in advance” what the others will do in specific situations. We see this type of self-synchronization in many team sports, football being one example. Football contains operational phases that are very similar to the planning and execution phases of a battle. During the planning (the huddle in between plays) the next increment of the attack plan is developed by the offense and the next increment of the defense plan is developed by the defenders. When the play commences each player begins to carry out assigned tasks. However, the situation changes; the “plan does not survive contact with the enemy” and it must be adapted (repaired). Each player expects certain actions from the others to respond to the current situation. If they all perceive the same situation, and if they are well trained to respond in a predetermined way, they will adapt their individual tasks in a way that supports a fully coherent, synchronized change in the full set of tasks that are part of the current plan for that play.

Self-synchronization requires an ability for individual elements of the force to adapt their own actions to meet changes in the situation with high assurance that coherency across the force and unity of command can be maintained without detailed centralized control..

We can make giant strides toward a self-synchronized battlespace by building upon the network-centric capabilities that are now being developed and fielded. We need to augment the situation awareness systems since they do not provide sufficient common understanding and appreciation across the force. Once the decision support technology is available, we need to adapt doctrine, concepts, and TTPs to use this distributed decision-making capability to full advantage.

The foundation for the self-synchronized battlespace is situation awareness, but the use of that awareness to dominate the enemy is the real goal.

We also need to build an oversight system that can track distributed self-synchronized actions to whatever extent is necessary to assure that we can still provide centralized management of the situation within allowable control limits. That is, we give the distributed warfighting elements significant ability to control their own actions, but we also monitor to provide control by “exception” (that is by negation or by direction as needed) to keep the entire flow of the battle within a range of actions acceptable to the commander.

Distributed control or self-synchronization must always be implemented within a trusted monitoring and control environment that allows strong centralized control to be reimposed whenever needed.

If we are successful in implementing the information processing, management, and dissemination systems that are now feasible, we will be able to use all of our sensor and weapons resources to their full effectiveness and will be able to degrade the effectiveness of the enemy’s warfighting systems. We may even be able to win without firing a shot simply by intimidating the enemy through evidently superior ability to use our maneuver and fires assets or by confounding his command and control processes. If we confront him with a force that responds in near real time to everything that he does or intends to do, his command and control problems could become insurmountable and cause him to quit the battle. In this way, information superiority may become both a “force multiplier” and a weapon in itself.

Beyond Awareness

Our perspective on situation awareness must be expanded beyond the simple notion of a common operational picture or consistent tactical picture. We must also be aware of what the information means (situation understanding) and what we need to do about it (military appreciation). Information superiority and battlespace dominance depend upon our ability to interpret battlespace knowledge and act accordingly, with a high degree of consistency across the force. It requires that we respond to the situation both reactively and proactively while maintaining the overall desired flow of battle implied in our plans and responsive to the commander’s objectives and priorities.

The challenge at this time is to complement our ability to collect, process, and disseminate information with a corresponding capability to use the information. The key is to use improved situation awareness to enhance performance in each of the warfighting functional areas, in the combat support functional areas, and for battle command as a whole.