Cognitive Systems Engineering as the Basis for a Revolution in Planning Support

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Effective support for Command and Control (C2) requires that the designer takes into account the results from a functional analysis and includes consideration of Cognitive Systems Engineering (CSE) based design principles. Planning, a critical component of C2 will be used to illustrate this point. ***How the designer conceptualizes planning defines the support that is provided to decision-makers that use the system.*** CSE's role is to provide C2 decision-makers with the support aids that they need to succeed and win.

Traditional Approach to Planning

While espousing speed and agility, current practice for C2 planning, like the development of an Air Tasking Order (ATO), tends to exhibit a batch-like feel, with large, 'off line' efforts focused on generating "The Plan." The focus for "The Plan" is on a single block of time. All decisions within that block are expected to be made prior to its start. However, within that block of time, decisions are made with varying levels of certitude because the information on which those decisions are based is unevenly available. This forces decision-makers to make the same level of commitment to a set of decisions despite the inherent variability within the set. Because of this, "The Plan" is kept afloat for only a short period, and even then, only with patches and repairs which are inevitably to be replaced by an equally short-lived successor "Plan." Within the military, the brittleness of this behavior can be observed in the use of branches & sequels, the inclusion of uncommitted resources in the plan, and the existence of special patch fixing groups like the Time Critical Targeting cell in an Air Operations Center.

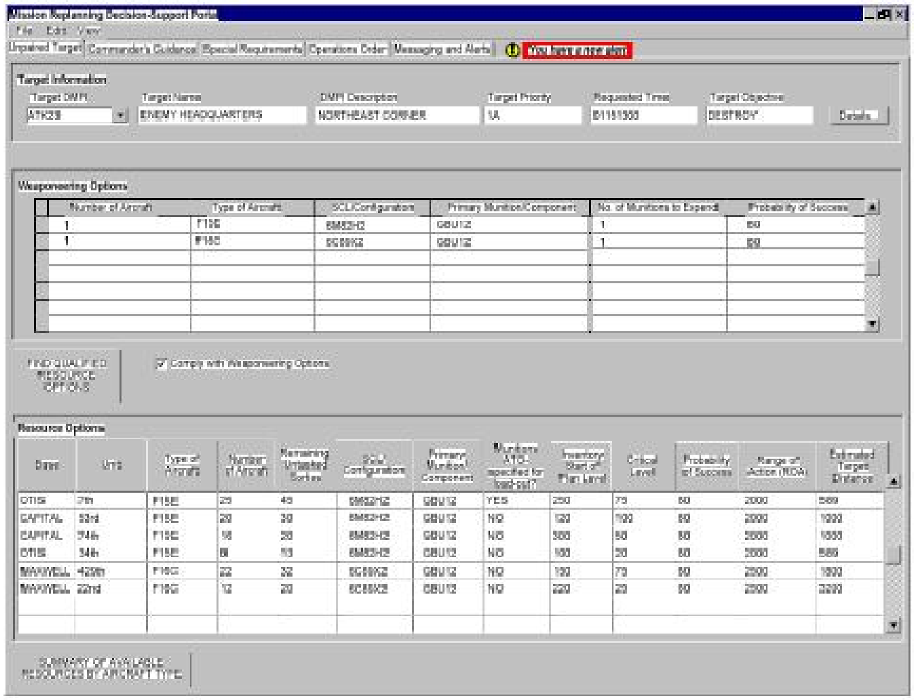

Figure 1. Interface Designed to Support Traditional Planning Process

When faced with this perspective on planning, CSE designers seek to support the cognitive work associated with building the document that is "The Plan." Predictably, this leads to supporting work processes rather than supporting the underlying cognitive work necessary for effective planning. Figure 1 provides an example of a system built using this approach. While this is an evolutionary improvement on the manual process previously used, it does not lead to major improvements in decision effectiveness. In fact, it is more akin to an electronic version of a paper form than to a true decision-aiding tool.

Planning as Dynamic Decision-Making

Static answers, like "The Plan," that attempt to identify optimal solutions for a dynamic environment always fail, because the constraints that define "the problem" are constantly changing. The real world of agile C2 comes with the realization that it is now, and really always was, a matter of "modifying a plan in progress" within a set of dynamic constraints.

The batch process that characterizes much of the current planning practice places unnecessary constraints on the decision-maker. In addition, it does not reflect accurately the functional relationships in the world that the decision-maker is attempting to impact. ***The functional relationships, which define "the physics" of the problem, each has their own distinct mapping to physical objects in the world, as well as their own temporal coupling constants***. That is, the rate at which one functional process impacts another functional process is tempolabile and varies from function to function; any attempt to force all functions into a single coordinated cadence is doomed to failure.

From a functional perspective, a plan is nothing more than a series of pre-made decisions about future actions that are used to impact specific functions or functional relationships. As such, the C2 planning process should be regarded as a continuum, made up of decisions in varying states of existence. The first state consists of decisions that have been previously implemented. These decisions must be assessed to determine the extent to which functions that were targeted were impacted. This information is critical, for decisions in the later states of existence will depend on the success of earlier decisions. The second state involves those decisions that are currently in the process of being executed. The decisions must be monitored to determine if they were executed as planned or not. The third and final state of existence pertains to those decisions that are waiting to be executed. Future decisions are based on assumptions about the functional relationships in the world, as well as assumptions about the current state of those functions. Because no decision-maker ever has perfect knowledge of the future, these decisions should be thought of as tentative, subject to future modification.

In order to effectively support planning, what is needed is a new fundamental basis for C2 concepts, grounded in a CSE analysis, which can guide:

- the development and selection of appropriate technologies,
- the concept of operations of the command structure, and
- the restructuring of the needed information systems.

Researchers must abandon trying to treat C2 planning as if it were merely a series of inputs to a control system. For example, using a model of the physical system, and calculating an error signal representing the difference between the world and the desired state as the basis for planning decision will not enable the design of effective support. This only will lead to tools focused on producing "The Plan" – a document – rather than developing tools that aid the decision-maker with the cognitive work associated with making trades-offs between different sets of actions, resource allocations, and temporal sequencing.

The shift from viewing planning as a series of static documents to be composed, to viewing it as a dynamic set of interactions with the environment means that:

- A plan should be viewed not as a singular entity, but as an aggregate of fine-grained, individual future decisions.
- Plans are recognized as tools that allow decision-makers to have appreciation for discrepancies between expectancies and actual events.
- Planning is regarded as a continuum.

By releasing the artificial constraints of focusing on "The Plan" as a whole, it can be seen that ***a 'plan' is simply a collection of decisions: past, present and future***. As time progresses, the decisions for the future come to be executed in the present, the 'errors' in the predictions force some decisions to be adjusted or replaced, and new decisions need to be 'painted into' the scene to fill the newly exposed landscape now coming into view over the horizon. By removing the requirement to have a complete, encapsulated Plan, and replacing it with a smoothly evolving, dynamic collection of temporally intertwined individual decisions constantly being reevaluated, reexamined, and revised, it is possible to achieve a kind of agile, dynamic command and control not previously feasible.

Notice how the visualization in Figure 2 differs from the interface in Figure 1. The shift from supporting the development of a static planning document to support the management of a set of decisions in varying states of existence has a profound impact on what is portrayed.

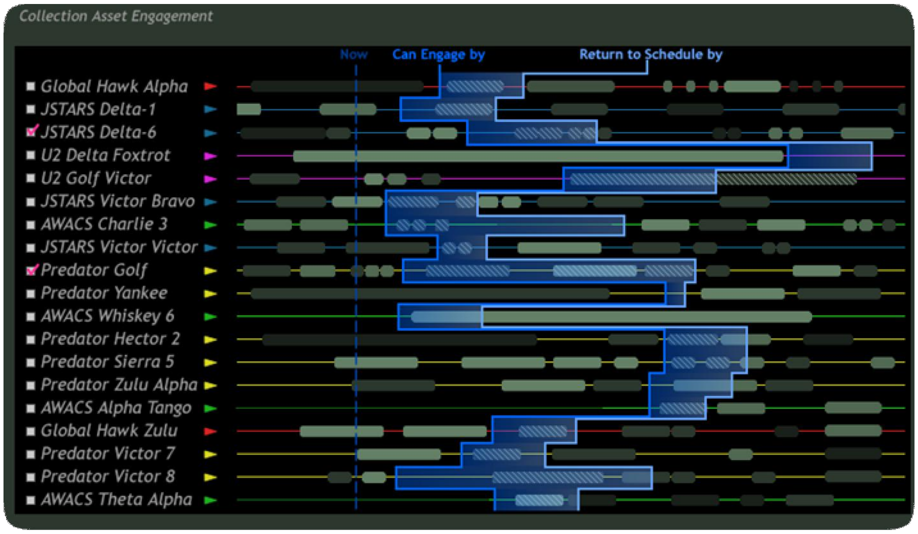

Figure 2. Interface Designed to Support Dynamic Planning Process

Support Needs for Dynamic Planning

In order to provide support for dynamic planning, a system must provide observability and directability into its underlying algorithms. Alone, well-designed technology capabilities are not sufficient for effective support. The underlying "business layer" of a system must be paired with an effective, decision support interface, to create a Joint Cognitive System, an integration of man and machine, that will improve overall decision effectiveness.

Building enhanced observability of the technology capabilities into the system enables decision-makers to comprehend, at a significantly deeper level, the allocation algorithm, and how it is making the inferences based on mission characteristics (e.g., mission location, en-route / egress flight paths, congestion areas). It also becomes easier to comprehend make intelligent asset assignment tradeoffs. The decision-makers will have insights into the processes being utilized by the automation, will gain an understanding of why the automation is doing what it is doing, and, perhaps most importantly, will have control over what it will do next.

Providing decision-makers with explicit, positive directability of allocation algorithms affords them the ability to effectively supervise and direct asset coordination and management technology towards the best possible solution. From the enhanced level of control, there will be a totally new level of interaction. Decision-makers will be able to direct the automation in a manner that keeps them in control of the situation by directing the automation.

Prior experience has shown that two approaches– ***Constraint Directed Search (CDS) and Reactive Re-Planning (RRP)—enable the effective coordination and management of C2 decisions***. CDS is needed because every action that a planner intends to make will have an impact on multiple resources. This level of complexity is too great for a planner;

human decision-makers just cannot keep these many dimensions straight in their head. The management and scheduling of assets in a C2 domain is a prime candidate application area for CDS. CDS is a powerful configuration and scheduling technology founded on the use of a rich constraint representation to not only model the problem knowledge space, but also, more importantly, to guide the search to a solution.

For even simple models of scheduling, the search process often depends on heuristic commitments, propagation of the effects of commitments, and the retraction of commitments in the event of a dead end. Utilizing CDS algorithms for dynamic planning provides numerous benefits:

- CDS is able to quickly generate solutions for large, complex problem sets. Because the constraint space defines the search parameters, near optimal allocation solutions can be developed. More importantly, issues of pragmatic concern to C2 systems (e.g. speed, agility, and viability of the solution) are given priority over a fixation on optimality.
- The decision-maker controls the generation of the plan to explicitly reflect command prioritization and intent.
- Results are achieved in a 'single pass' approach, avoiding the halting problems and commit/uncommit looping of other approaches.
- Results are, by definition, feasible (do not overcommit available resources).

CDS works best in over-constrained environments, because it focuses first on managing the bottlenecks, and it exploits the flexibility of other requirements to release the resource contention across the remainder of the solution space. This delivers a good, 'satisficing' solution, even for heavily over-constrained conditions. Allocation assignments are made at a fine-grained level and are collected together to form "a plan." The granularity of decisions produced will be the size of an asset's assignment over the necessary time window, allowing reactive replanning to replace fine-grained elements within a plan, even as the plan is executing.

RRP is an extension of CDS, in which the "Plan" is not treated as a singular entity; instead, "the plan" is considered an aggregate of individual decisions. RRP views C2 as a continuum of decisions: past, present and future. Reactive re-planning, a dynamic collection of temporally intertwined individual decisions constantly being reevaluated, provides for a level of agile C2 not previously possible. Given this conceptual shift, the benefits of this critical enabling technology become clear:

- The "plan" is a set of individual decisions that are easy to manipulate and acknowledge the physical resource and temporal couplings.
- Warfighters are able to control and 'influence' decisions across the time spectrum enabling dynamic C2.
- The Warfighter is able to bootstrap the process, developing a plan from a 'standing start'.

The inclusion of Observability and Directability into the system's design means that it is possible for the human decision-maker to manage powerful technologies and improve performance.

Summary

Static answers that attempt to identify optimal solutions always will fail, because the constraints that define "the problem" are constantly changing. Systems that are based on a static, batch-like approach similarly will fail to improve overall decision performance. The real world of agile C2 comes with the realization that it is now, and always was, a matter of "modifying a plan in progress" within a set of dynamic constraints. Any effective support system must provide the decision-maker with the tools needed to succeed and win. CSE's use of functional analytic methods and consideration of cognitive issues, places it in an excellent position to build systems that easily and effectively team with the decision-makers to dynamically manage C2 problems.