Lessons for C2 Investment from Capabilities-Based Planning

Implications for C2 in Difficult Environments

Topics: Concepts, Theory, and Policy; Experimentation, Metrics, and Analysis;

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ABSTRACT

An important theme in command and control (C2) research is the need to plan for "agility" in complex endeavors. Seeking C2 agility should be seen not as an exotic quest by theorists, but as implied by the strong version of capabilities-based planning (CBP) that emphasizes planning under uncertainty while making choices under a budget. Drawing on lessons from past CBP, the paper argues that key features of analysis for C2 agility should include conceiving the relevant scenario space; identifying a small "spanning set" of test cases to stress desired C2 capabilities for crucial challenges; estimating the value, cost and feasibility of addressing the various challenges so identified; aiding decision makers as they decide, under budget constraints, on which challenges to pursue and what requirements to specify; and defining appropriate measures of progress. Many impediments to such planning for agility can be anticipated based on the history of CBP, but the paper suggests strategies for dealing with them.

1. INTRODUCTION AND PURPOSE

This paper was stimulated by participation in the SAS-085 panel of the North Atlantic Treaty Organization (NATO), which is concerned with Command and Control (C2) Agility and Requisite Maturity.[1] The paper places the panel's work in the larger context of planning under uncertainty and capabilities-based planning (CBP). Some of the analytic methods that the panel has been using are unfamiliar to many readers and will likely be resisted, but they are examples of general cutting-edge CBP methods that are increasingly seen as representing best practices. This paper reviews those methods and relates them to the challenge of C2 agility. The paper draws on examples of C2 for complex endeavors (Alberts and Hayes, 2007) and a book-length discussion laying out interim concepts of the SAS panel (Alberts, 2011).

2. PLANNING UNDER UNCERTAINTY

2.1 THE PROBLEM OF UNCERTAINTY

Secretaries of defense and defense ministers know that they are providing military forces that may be needed for such diverse challenges as war fighting, deterrence, disaster relief, peace making, peace keeping, or dealing with civil unrest. Further, they understand that it is impossible to accurately forecast which challenges will arise or what form they will take. Even if war with a particular adversary can be anticipated, there are myriad variables such as: the proximate cause of war, prevailing international environment, who attacks whom, the alliances that will form, the degree of each side's mobilization, initial and subsequent objectives, and both strategies and tactics. Analogous uncertainties abound when contemplating military interventions. Will the operations require counterinsurgency? Nation building? Will they involve a heterogeneous and perhaps quarrelsome coalition? How long will the operations last? The list of uncertainties is long.

[1] The SAS-085 panel built on earlier work that developed the concept of C2 agility and the concept of characterizing the ability of a nation's force to employ different approaches to C2 in different circumstances. It referred to that in terms of a C2 maturity model (SAS-065, 2010).

2.2 CAPABILITIES-BASED PLANNING

Because of such uncertainties, in 2001 the United States adopted CBP. The original expression of intention was (Rumsfeld, 2001):

> A central objective of the review [the Quadrennial Defense Review] was to shift the basis of defense planning from a "threat-based" model that has dominated thinking in the past to a "capabilities-based" model for the future. This capabilities-based model focuses more on how an adversary might fight rather than specifically whom the adversary might be or where a war might occur. It recognizes that it is not enough to plan for large conventional wars in distant theaters. Instead, the United States must identify the capabilities required to deter and defeat adversaries who will rely on surprise, deception, and asymmetric warfare to achieve their objectives.

Actually, the U.S. Department of Defense (DoD) was pursuing multiple themes simultaneously:[2] planning under uncertainty (seen as a method of strategic risk management); assuring that forces would deter and dissuade,[3] as well as defeat if need be; focusing on capabilities rather than platforms; insisting on joint thinking when contemplating capability options; and exploiting technology to "transform the force" rather than merely modernize on the margin. C2 and Intelligence, Surveillance, and Reconnaissance (ISR) were seen as major elements of transformation, as reflected in the emphasis on network centric operations and precision fires.

Because the wars in Iraq and Afghanistan proved so different from what was contemplated during the writing of the 2001 QDR, Secretary Rumsfeld's initiatives are sometimes derided as having been misguided and overly technological. However, U.S. forces *have* in fact been transformed over the last twenty years. For the United States and some other NATO nations, precision weapons and network-centric operations are now the norm and, joint Intelligence, Surveillance, and Reconnaissance (ISR) is universally recognized as crucial to all force elements and to many elements of a NATO coalitional effort. Further, the partial successes in counterinsurgency and counterterrorism have been due to innovations and adaptations. Today's operations exploit high-technology ISR and drones, special forces, and ground-force units tailored for those missions. Although planners assuredly did not anticipate the last decade's struggles, the decade's experiences underscore the need to plan for adaptation rather than for stereotyped threat scenarios.

DoD's original implementation of CBP included some missteps and confusions. Some thought that the new approach was to be generic, without considering real-world threats. That invited the criticism that DoD wanted to prepare for invasions from Mars. Some saw CBP as about identifying capability areas, identifying alleged shortfalls, and asking for more money—a blank-check approach comfortable to organizations but not to those with an eye on budgets. Lastly, the Joint Staff created a complex and burdensome organizational process. This paper is *not* about the various problems with CBP as initially implemented, or about subsequent improvements. Rather, it is about core aspects with enduring validity.

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[2] See Davis (2010) for defense planning under Secretary Rumsfeld. The larger book also includes critical chapters dealing with, e.g., civil-military relations (Cimbala, 2010).

[3] The emphasis on deter and dissuade was the Bush administration's way of addressing needs that the Clinton administration had discussed under the rubric of shaping the environment.

The remainder of the paper uses the following definition from 1990s work that influenced DoD's embrace of CBP in 2001. Although not official, it has been cited widely and is applicable to strategic planning more generally. The definition and explanation are (Davis, 2002):[4]

> Capabilities-based planning is planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances, while working within an economic framework.
>
> This seemingly innocuous definition has three important features. First, the notion of planning under uncertainty appears in the very first clause: uncertainty is fundamental, not a mere annoyance to be swept under the rug. Second, the idea is to develop capabilities—i.e., the general potential or wherewithal—to deal not with just a well-defined single problem, but rather to deal effectively with a host of potential challenges and circumstances…Third, this is to be done not with the largesse of a blank-check policy (preparing for anything that might conceivably arise), but rather while working within an economic framework.

At this point it is perhaps evident that:

- The quest to achieve C2 agility, and to build the need for such agility into the basic fabric of C2 planning, is a specific example of capabilities-based planning.
- The philosophy of seeking C2 agility should not be controversial, but rather seen as something embraced by and even insisted upon by top policy makers.

The latter point is significant because organizations typically resist capabilities-based approaches as discussed in the last section of the paper. Such resistances should be anticipated and overcome.

Sections 3-7 address: confronting the extent of uncertainty; pragmatic simplification; performing exploratory analysis to assess options for diverse possible cases; presenting intelligible results; supplementing analysis with an attribute approach; and anticipating and dealing with impediments to progress.

Limitations of space prevent touching touch on two other important analytic topics relevant to CBP: developing options with adaptiveness in mind and using strategic portfolio analysis to help make economically constrained choices in a framework with multiple objectives, including risk management (Davis, Shaver, and Beck, 2008; Davis, Shaver, Gvineria, and Beck, 2008; Davis and Dreyer, 2009).

3. CONFRONTING THE SCOPE OF UNCERTAINTY

3.1 ANALYSIS ACROSS POSSIBILITY SPACE

Progresss in uncertainty analysis is due to a confluence of four developments as shown in Figure 1 from a recent review (Davis, 2012). Most familiar perhaps is technology: modern computers and software allow analysis that would have been inconceivable in the early days of

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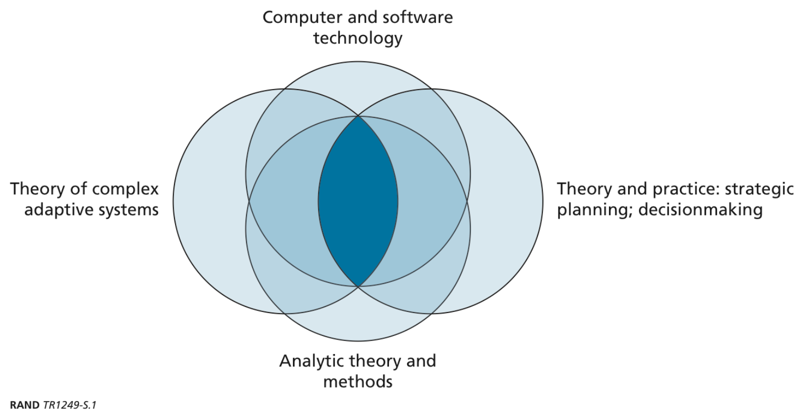
[4] A number of sources cite the definition (Technical Cooperation Program, 2004; National Research Council, 2005; Caudle, 2005; Fitzsimmons, 2007; De Spiegeleire, 2011). Other sources refer to CBP as a method of managing risk (Hicks and Ridge, 2007). Still others define capability as "ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks" (Chairman of the Joint Chiefs of Staff, 2011). That last definition arose from the need to spell out the "contract" so that the military knows for what it is responsible without having open-ended obligations. The definition's call for specificity, however, can undercut the broad philosophy unless the requirement specifies a range of conditions.

systems and policy analysis, such as examining a vast possibility space when considering options for the way ahead. Technology, however, is only an enabler. Developments in strategic planning and the aiding of decisionmaking, and in analytic theory and methods, have also been fundamental. These in turn have been influenced by the theory of complex adaptive systems, which recognizes that behaviors of social systems can be inherently impossible to predict with confidence. Nonetheless, behaviors can often be anticipated, nudged, and occasionally controlled.[5]

Figure 1. Confluence of Influences



Much modern work focuses on “deep” uncertainties that cannot adequately be addressed with normal sensitivity analysis. Deep uncertainty has been studied at RAND for some years, but is also described delightfully in a popular work on "black swans" (Taleb, 2007).

A cross-cutting theme when dealing with uncertainty is a principle relating to flexibility, adaptiveness, and robustness (the FARness Principle). This admonishes finding strategies that provide: future flexibility for taking on different missions or objectives, adaptiveness to deal with unanticipated circumstances, and robustness to shocks such as unanticipated adverse advents. Authors often use “planning for adaptiveness” or “robust decisionmaking” to mean much the same thing. Regrettably, a number of English-language words have overlapping meanings. What matters here is that *the search for C2 agility is in precisely the same spirit as the FARness Principle*.

To dramatize how embracing FARness or agility should affect analysis, consider Figure 2. The top compares two options by performance in a standard case. Both options meet the requirement, but Option 1 is better. This, arguably, is the canonical way that analysts compare options. The bottom half of the chart illustrates a simple version of the new perspective. It compares options by how well they would do across a possibility/scenario/case space, with the "standard case" being merely one point therein. Clearly, Option 2 (right pane) is superior overall, though not not for the standard case. Option 2 exhibits more FARness or agility. This view of the problem is the analytic essence of planning under uncertainty.

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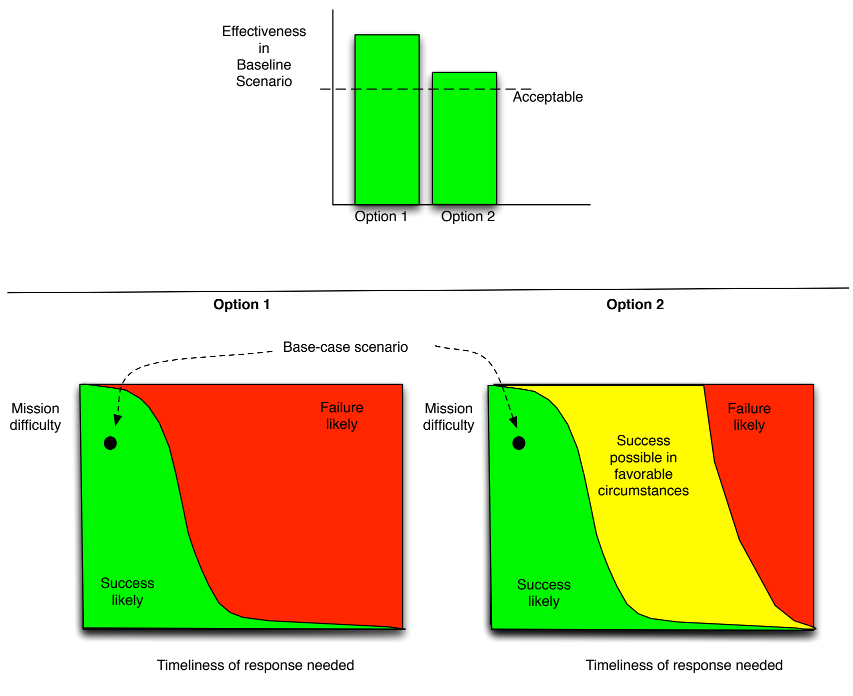
[5] Empirical evidence from business planning is of interest (Grant, 2003). It discusses "planning for emergence," i.e., planning to be able to allow a new strategy to emerge when it is justified by the course of unanticipated events.

Figure 2. Comparing Options Across an Uncertainty Space Rather Than for a Standard Case



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3.2 DIMENSIONS OF SCENARIO SPACE

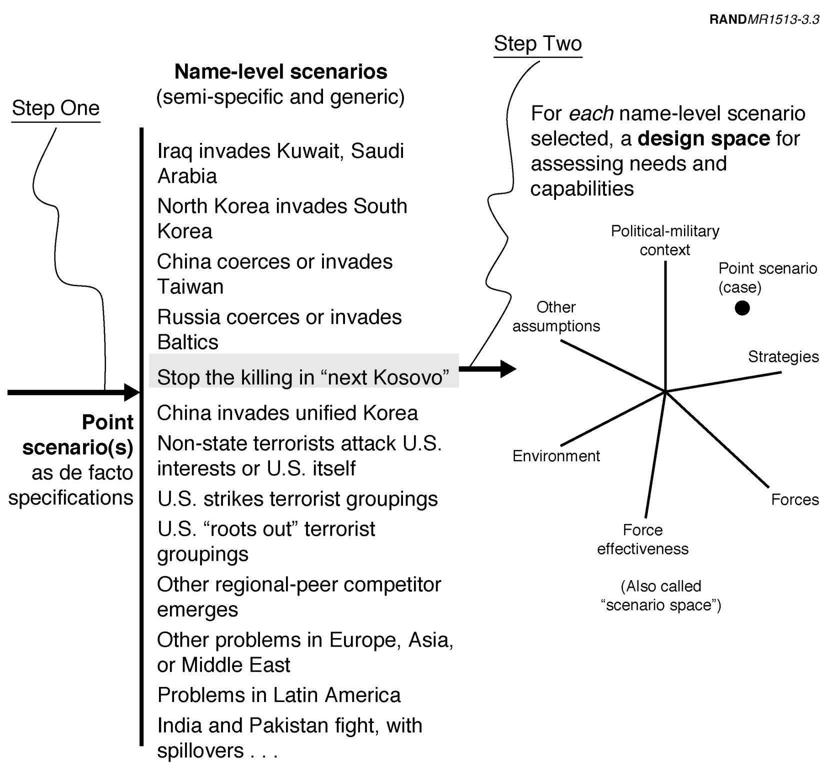
The next question is how to define the scenario space (the term used hereafter, rather than referring to possibility/scenario/case space). The most important challenge is confronting the deep uncertainties. Figure 3 illustrates an attempt to conceptualize the scenario space for U.S. defense planning a decade or so ago (Davis, 2002). On the left is a list of "name-level scenarios" that emerged from systematic thinking and brainstorming. The items are called "name level" because they say nothing about the myriad details that fully define a scenario. Imagine that we had a perfect simulation model that could predict exactly what would happen in a particular scenario—if only we provided all the necessary input data. For something like a large campaign model, that might involve hundreds, thousands, or tens of thousands of data items. Arguably, for warfighting analysis, they would be in one of the six categories shown as dimensions of scenario space on the right. In other contexts, such as stabilization operations, economic and sociological dimensions would be crucial to analysis, not just discussion. This is discussed in a recent review (Davis, 2011).

Using the scenario-space construct open minds by confronting important uncertainties. An example on the dimension of "strategies" is whether the adversary will behave in a convenient way or instead change the rules by adopting a so-called asymmetric strategy. Political-military context includes such sensitive matters as who one's allies are, who is allied with the adversary, and what one's allies will do (grant overflight, provide bases, send soldiers,…?). It is important also to mention the axis called "other assumptions." Many of these have to do with deeply buried model assumptions that are seldom discussed even though they are very dubious. Is local attrition truly described by a Lanchester equation? How fast, really, would a future army move if not under severe attack but knowing that it would be shortly? For intervention operations, how much (if any) benefit is achieved by increasing foreign aid, increasing the size of the counterinsurgency force, or pursuing strategic communication? Algorithms for such matters may be included in the model, but to imagine that we know either the true "laws" (if they even exist), much less the parameter values, stretches credulity.

It is often valuable in studies to begin with a scenario-space discussion so that the study team is aware of the variables at work and conscious about the degrees of freedom that will be varied in analysis. The study can then highlight and vary important assumptions that otherwise would have been held constant. It can also help identify important hedges. Such work is decidedly unlikely to anticipate all surprises, but it can anticipate many. More important, by opening minds it encourages planning for adaptiveness.

Again, the tenets of this general approach strongly support the philosophy of seeking agility in C2 systems and approaches. They also support a very different approach to related systems-of-systems development than has been common in system engineering. They suggest assuring agile capabilities rather than designing to detailed requirements that make sense only with the conceit of imagining that the system's future applications can be accurately predicted.

Figure 3. A 2002-Era Scenario Space for Defense Planning



Source: Davis (2002).

4. PRAGMATIC SIMPLIFICATION

4.1 TOWARD CONCRETENESS AND REASONABLE APPETITES

A problem with scenario-space thinking is that it is abstract and unbounded. Pragmatically, simplification is needed. This could mean "narrowing," but in strategic planning it is often preferable to simplify by aggregation rather than by elimination. For example, "warning time" is an aggregation of numerous time-related variables that affect when one can begin in earnest to prepare for an upcoming event. "Type operation" is another aggregate variable, one distinguishing among, e.g., humanitarian relief, peacekeeping, peacemaking, counterinsurgency,…and total war, all of which are themselves aggregate concepts.

After thinking broadly about the n-dimensional scenario space and stretching the imagination, it is usually possible to segment the space so that different regions correspond to different classes of challenge.[6] This procedure is familiar to scientists and analysts, who are good at making distinctions. It is also familiar to high-level designers, such as an aeronautical engineer who must worry separately about, say, performance at very high and very low altitudes, and at both supersonic or subsonic speeds.

The next step is to find "representative" points within each region. This is often done in a slap-dash manner, but should be an ideal task for a careful but imaginative analyst, rather than a scenario spinner, essay writer, or committee. The intent is to put such representative scenarios together in what can loosely be called a "spanning set of test cases." Each test case should "stress" the options being evaluated in a different way (Davis, Shaver, and Beck, 2008; Davis, et al., 2008a). An option that does well in all of the test cases should provide the capabilities necessary to cope well with a real case when it arises, even though it will probably not be any of the test cases. This concept was adopted qualitatively in the 2010 QDR (Gates, 2010).

This may seem like nothing more than the old admonition to plan for the worst case, but that admonition is silly because the many challenges stress capabilities in different ways and are often contradictory: there exists no single worst case. For example, a country with a hostile neighbor should worry about both short-warning and long-warning scenarios. There is no single scenario that addresses the issues of both. Further, concatenating numerous pessimistic assumptions uncritically leads to uselessly impossible test cases.

Interestingly, the approach called for would be a straightforward extrapolation of using familiar defense-planning scenarios *if* those scenarios had been developed from careful analysis to stress the right capabilities in the right way. In practice, however, the assumptions built into the specified versions of the planning scenarios often derive from other considerations, such as: strategic blind spots (oh, the adversary would never do that…); organizations wanting assumptions that will allow their desired programs to look good in subsequent simulations, thereby avoiding the need for disruptive changes; or unimaginative conventional wisdom.

Identifying the good test cases requires the analyst to worry about what cases are plausible (taking into account the possible reasoning of adversaries and other actors) and what capabilities are feasible, affordable, and otherwise sensible. An analyst, however, cannot simply decide at his level that the test case should, e.g., require ubiquitous persistent high-resolution real-time surveillance. It follows that the simplification to find a spanning set of test cases must involve parameterizing key variables, conducting first-order systems analysis that considers feasibility, effectiveness, and costs; and then distilling the results for discussion with policy makers. As

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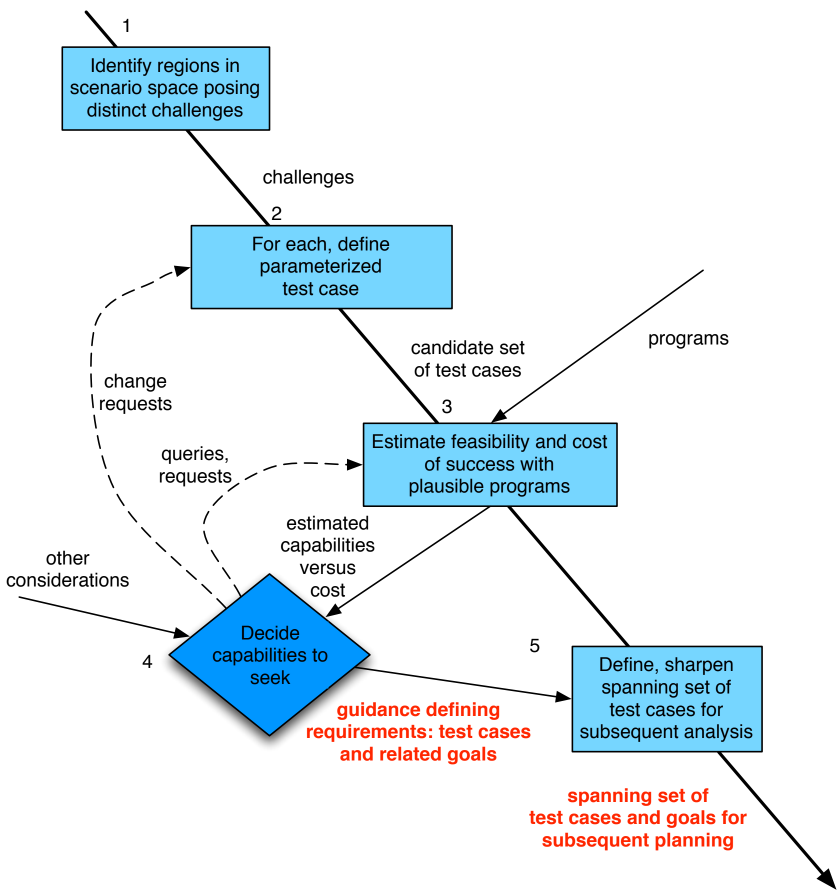
[6] The term "region" should not be construed literally and the concept is best understood with set theory.

indicated in Figure 4, analysis should be iterative, with policy makers deciding along the way what capability options they want entertained in detailed evaluation, i.e., how large their appetites actually are.

Such a process can generate a small spanning set of test cases, with other test cases omitted. This smaller final set reflect the true "requirements" to be fulfilled. They may be quite different from what portions of the organization would like to believe are requirements. They may be different because of concerns about feasibility, affordability, or priorities, or because of recognizing a better way to proceed than what the organizations proposed. The final requirements should include requirements for risk reduction causing hedges to be included in options.

Figure 4. Iteration



Source: Adapted from Davis et al. (2008).

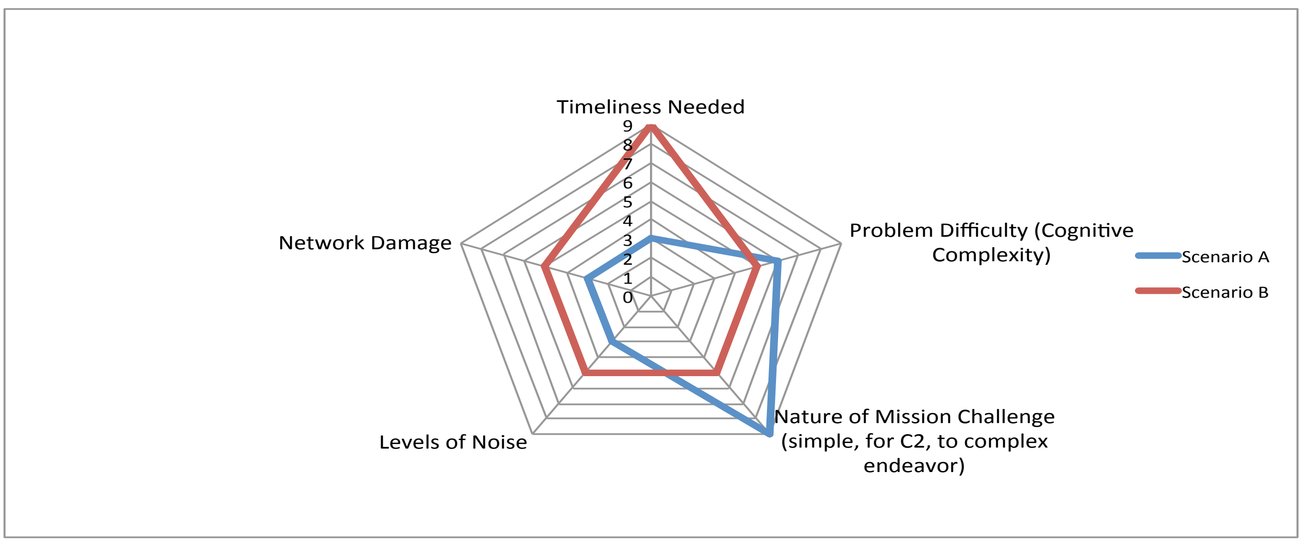
4.2 RELATIONSHIPS TO C2 AGILITY ANALYSIS

The concepts described above apply well to achieving C2 agility. Indeed, SAS-085 has a concept called "Endeavor Space," which plays somewhat the same role as the scenario space above. The relationship between it and scenario space, however, is neither straightforward or, as yet, well characterized.[7] As of 2012, the panel recognized five dimensions (Alberts, 2011, pp. 283ff): (1) the timeliness needed for C2 response, (2) problem difficulty (essentially the cognitive complexity of the military challenge), (3) the nature of the mission challenge (e.g., straightforward operations driven by industrial-style warfare versus complex endeavors with multiple coalition members and no supreme and fully empowered commander), (4) levels of "noise" when the C2 system interprets the situation, and (5) damage to the network.

Figure 5 uses a spider plot to characterize two notional scenarios in this conception of Endeavor Space. Scenario A involves a particular complex endeavor, perhaps with a loose coalition of nations with overlapping but different objectives, one that rejects having the unified command beloved in military doctrine. The scenario also includes considerable cognitive complexity reflecting, e.g., the variations in doctrine and intention of the coalition elements, the intentions of local factions, imperfect and often ambiguous communications, and so on. In contrast, Scenario B is more militarily classic; it lacks some of the complexities, but posits the need for extreme timeliness despite a degree of network damage and noise.

Speculatively, wide-ranging discussion about such cases may identify naturally different regions of the space for which to have test cases. First-cut versions of such test cases have been incorporated in ongoing experiments using the ELICIT model and other tools (Alberts, 2011, pp. 283ff).[8] Developing more carefully chosen and defined test cases will require additional effort.

Figure 5. A Spider Plot of Contrasting Cases in Endeavor Space



[7] Endeavor Space is the part of scenario space that is "sensible" to consider in C2 work. For example, attributes of the C2 system are irrelevant to portions of scenario space that involve impossible or trivial challenges (e.g., very large and capable, or small and overmatched adversaries; or requirements for leisurely C2).

[8] ELICIT is the DoD’s “Experimental Laboratory for Investigating Collaboration, Information-Sharing, and Trust.” It is a computer platform that enables experiments with human teams, teaching, and analysis. It includes model agents that can formalize some of what is learned from human experiments. See http://www.dodccrp.org/html4/elicit.html.

5. EXPLORATORY ANALYSIS

5.1 THE BASIC CONCEPT AND THE PROBLEM OF DIMENSIONALITY

Evaluating capability options across a scenario space or a portion thereof does *not* mean conducting standard sensitivity analyses around some baseline, one variable at a time. Rather, it means evaluating how a given option would perform for all combinations of input conditions. This is *exploratory analysis* (Davis, 2002), which looks at the entire space of possibilities and may not even recognize any base case as being meaningful.

Exploratory analysis is easier said than done. Having 10 uncertain variables, each with 3 possible values, would mean 3^{10} cases (59,049). With 100 variables, even with only 2 possible values, the cases would number 1.27×10^{30}. Even with infinitely fast computers that could run all the requisite cases, however, what we would do with the results? If those making decisions want to understand and *reason*, the dimensionality has to be reduced drastically—but not by ignoring uncertainty to focus on some allegedly "best-estimate" case.

5.2 MULTIRESOLUTION MODELING AS AN ENABLER

If one is fortunate enough to have a validated big model (or at least a well-accepted big model) to use in analysis, a version of exploratory analysis can be accomplished by holding the vast majority of inputs constant and varying only those known from experience to be important and relevant. One example in work from the 1990s used the Joint Integrated Contingency Model (JICM), a campaign model (Fox, 2003). In other applications, however, some among the many variables held constant will often be far more important than realized, especially if the model's developers are not present to remind analysts of subtleties.

A better way to proceed is with a multi-resolution model or family of models (Davis and Bigelow, 1998; Davis, 2003) so that exploration can be accomplished by the low-resolution version with a relatively small number of high-level variables.[9] If this is done well, the analysis will still reflect the full *breadth* of the problem, while sacrificing detail. This approach is particularly attractive if the variable hierarchy reflects top-down thinking in which the top-level variables correspond to objectives. The result is then directly relevant and cognitively meaningful to policymakers. After discovering which of the top-level variables are of most concern, the analyst may, if necessary, zoom in for more detail on those variables (either by turning on greater resolution or moving to a separate higher-resolution model). This is important if the uncertainties of the high-level parameters are not well understood or large, and if it is necessary to understand how to reduce them.

Multi-resolution modeling is seldom feasible on an exact basis because it typically depends on lower-level variables having a hierarchical relationship, which is seldom the case.[10] However, in most problems a *near*-hierarchical relationship exists, which is good for approximate

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[9] Big models can have optional lower-resolution options, especially with a nearly modular design and a clear interface identifying interactions. Which functions are treated with lower resolution can then be a run-time decision. An alternative is to spin off simpler models so as to have a rough family of models. In viewgraphs, this is common, with the model used in analysis being shown as fed by higher-resolution models, as in the pyramid of models with levels for engineering, engagement, mission, and campaign analysis. In reality, multi-resolution modeling can be quite challenging and is very different from the naïve image of a model calling a higher-resolution model as a subroutine. A good deal of analyst thinking is needed to connect the levels.

[10] An exact diagram of a relatively detailed model will typically look like a bushy network rather than a hierarchy..

treatments.[11] Such multi-resolution structures do not arise naturally from bottom-up simulation modeling, but rather come about when someone takes a top-down view or estimates results as the result of an idealization plus increasingly more complex correction terms. A similar top-down view is essential in the discipline of systems engineering.

Two Ways to Obtain the Lower-Resolution Model For Exploratory Analysis

Ideally, the low-resolution version of a multi-resolution family will be based in approximate theory (e.g., the ideal gas law, viscous-less flow, or, in military affairs, a model of precision fires based on the product of sorties per day and kills per sortie). The author and RAND colleagues frequently develop relatively simple but sensible "capability models" in studies, even if we have access to more detailed models. We try to represent the operational process correctly, but with high-level parameters for, e.g., decision time, C2 delay time, probability of detection, and probability of kill. We establish the range of parameter values drawing on higher-resolution work, empirical experience, or expert judgment.[12] The most important results of our analysis come from using these models parametrically.

If no one has worked out such a starting theory (e.g., built a good "capability model"), but a validated detailed model exists that can be used for experimentation, then a low-resolution model suitable for analysis can be developed as a *motivated metamodel* (Davis and Bigelow, 2003), one generated by analyzing the experimental data statistically. In contrast to most “response-surface” work, the key concept is to specify that the regression analysis pivot around an approximate and intuitive simple model.[13] That might be based on a combination of crude "physical" reasoning and dimensional analysis. The equation below illustrates this by imagining that we have reason to believe that results Q should be proportional to X, the square of Y, and the inverse of W, and to decay exponentially with time T and Z. If the reasoning behind this is roughly right, then regression analysis will report that the terms within brackets, after the 1, are relatively small. If so, then there is a built-in "explanation" to be used in reasoning and discussion with policy makers. This approach is drastically different from merely having a statistician analyze data with his standard tool kit.

$$Q = C_1 \frac{XY^2}{W} e^{-aZT} \left\{ 1 + C_2 X + C_3 Y + C_4 W + C_5 Z + C_6 a + C_7 \right\}$$

As an analogy from high school chemistry, the relationship of a dilute gas's pressure P, volume V, and temperature T can be understood by the ideal gas law, which can be thoroughly understood, plus some correction terms. That is, PV/(NkT) = 1 + correction terms.

[11] For discussion of nearly decomposable systems motivated by living systems, see Simon (1996).

[12] Factors may be elicited from experts with different perspectives and specialties, but the model should then relate them coherently. One approach of this type has used “factor trees” in modeling counterterrorism and other phenomena requiring social science (Davis and Mahoney, 2013). Influence-net approaches are an alternative, but with diagram nodes having a probabilistic meaning.

[13] What is “intuitive” can vary with individual, but the matter is often not so subjective. For example, expressing effectiveness of something as a product of approximately independent probabilities for steps along the way in a process will be broadly intuitive, perhaps after explanation.

Recognizing Essential Nonlinearity

It is often the case in analysis that one should evaluate an option as worthless if *any* of several critical components fails. An army is nearly useless, for example, if it has no logistics, or if it has no weapons, or if its command and control is hopelessly bad. This implies that effectiveness is fundamentally nonlinear. It follows that if we want to do some kind of computer-driven evaluation (or to interpret computer experiments, we should assume an effectiveness function that anticipates critical components with an initial multiplicative factor comparing each component to a minimum acceptable level, i.e., a threshold. Thus, if we thought that variables X, Y, and Z are probably pretty much additive in determining effectiveness, but only so long as they exceed threshold values, then the form for testing might be as follows with Q being the observed outcome and items on the right being variables or constants (C_1, C_2…).

$$Q = C_1 T(X,Y,Z;X_{0,}Y_{0,}Z_0)\left\{1 + C_2 X + C_3 Y + C_4 Z\right\} + C_5$$

where

$$T = \Delta(X \geq X_0, Y \geq Y_0, Z \geq Z_0)$$

$$\Delta(\mathbf{V}) = 1 \text{ if } V_i\text{=1 for all i, and 0 otherwise}$$

Such motivated meta modeling has proved powerful in past studies[14] and will probably prove useful in studying C2 agility.

5.3 DETERMINISTIC AND PROBABILISTIC APPROACHES TO EXPLORATORY ANALYSIS

Given a simple evaluation model from theory or motivated meta modeling, we can perform evaluations across the uncertainty space. Several ways exist for doing so (see also National Research Council (1997).

Deterministic Exploratory Analysis

Exploratory analysis can use a deterministic version of the model, but vary the values of the key input parameters. A first-cut exploration might assign just two or three values for each such parameter. Subsequent exploration might add additional values for a very few variables so as to understand the outcome landscape in more detail.

A straightforward but computationally intensive approach is to run all of the cases implied (what statisticians call the full factorial analysis). This has the advantage of often generating smooth output graphics with no glaring holes—something valuable for communication and, critically, causal reasoning. This appeals to those who prefer theory-driven analysis rather than let-the-data-speak analysis.

Probabilistic Exploratory Analysis

Probabilistic modeling is a sharply different approach in which one characterizes the uncertain input variables with probability distributions and then uses Monte Carlo sampling to generate the probability distribution of outcomes. This is easy with modern laptop software that facilitates Monte Carlo work with built-in distributions and good interfaces. Unfortunately, the methods are "easy" only because, in most cases, the analyst implicitly assumes that the variables

[14] Examples have involved interdiction with precision fires in mixed terrain and different movement strategies (Davis, Bigelow, and McEver, 2000), an epidemiological model of terrorism (Davis, Bankes, and Egner, 2007), and a computational social-science model of public support for terrorism (Davis and Mahony, 2013).

are statistically independent, which is often absurd. Second, the approach buries information on cause and effect,[15] which is directly visible in displays from deterministic exploration. It is that cause-effect information that is of most interest to many senior reviewers or policy makers. Third, of course, in problems of deep uncertainty, one does not know the probability distributions to use, in which case the elegant output displays may be bogus.

Hybrid Approach

Often, only a few variables are particularly important and uncertain. It may then be natural to treat the special few deterministically, but to vary the others probabilistically, so long as doing so does not obscure important dichotomies.[16] This has many of the advantages of both deterministic and probabilistic modeling.[17]

5.4 SEARCH AND VISUALIZATION

General Approaches

Manual Approach. A number of methods and tools exist for exploratory analysis. For many problems, straightforward interactive work with the model can lead the analyst to identify the interesting regions, as in identifying what variables absolutely must be controlled for success and what combinations of other variables matter. The results may be remarkably easy to understand in retrospect. Procedurally, this approach may mean looking at multi-dimensional displays (e.g., Figure 6) and experimenting with what variables are held constant and which are varied along, say, the X, Y, and Z axes (perhaps with the color of a point indicating the quality of outcome). After such experimentation, one discovers which variables do and do not matter and what corners of the scenario space are important. With further experimentation, one can arrange the variables and the directionality of the axes so that, for example, "good" results appear at the bottom left and "bad" results appear in the top right.

Figure 6 illustrates what can be done with modern laptop tools, in this case the commercially available *Analytica* modeling system (Davis, 2002). The computer has already run, in seconds, about 10,000 cases varying 11-13 variables with 2-3 values each. The analyst's display is as in the figure and the analyst can change the values of any of the variables at the top of the display by merely clicking on the menu items. The display updates almost instantaneously. The analyst can explore the n-dimensional space by closing his door, sipping his coffee, concentrating, and navigating. In practice, the patterns become evident relatively quickly, at which point he can

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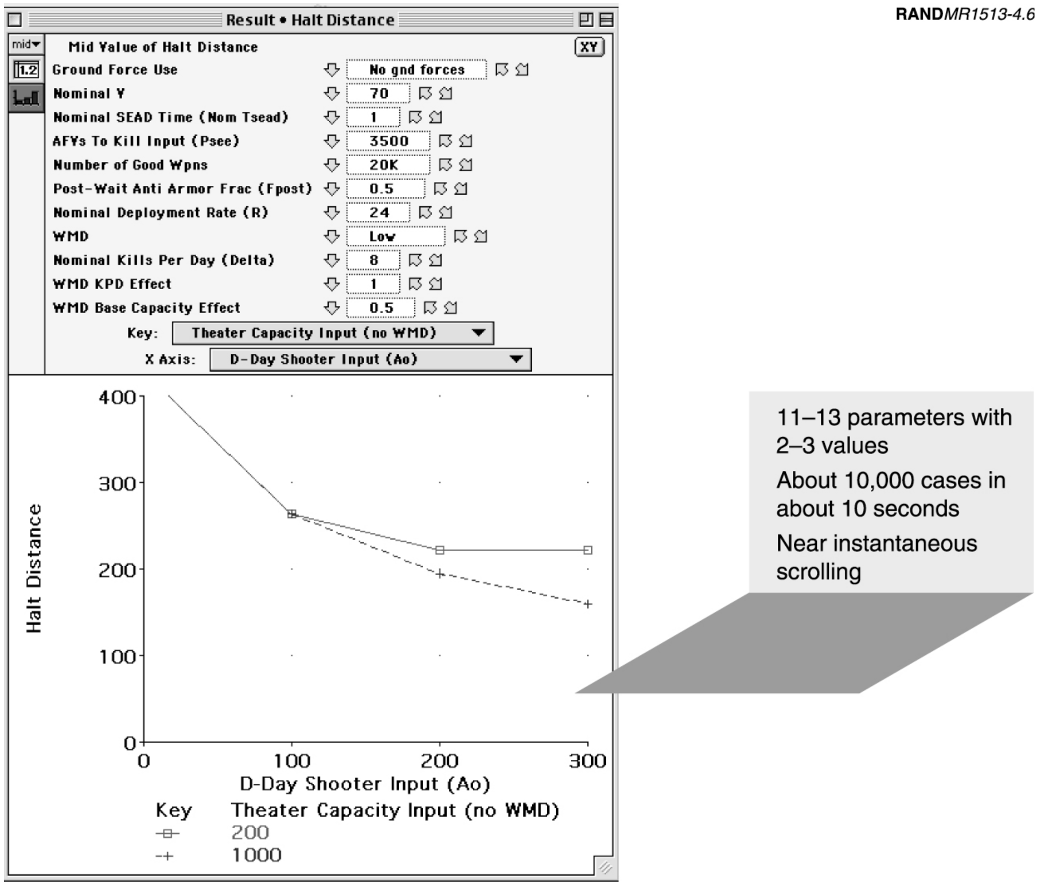
[15] The information is not necessarily lost because the analyst can keep track of the input values by run, and can go back to that data base to find, e.g., which cases produce "good" outcomes.

[16] If results are very good and very bad, if a variable X has value X_1 or X_2, respectively, then one doesn't want to report the average result (marginal), hiding the potential for very different results. A classic example is using Lanchester equations with the 3:1 rule. As revealed by stochastic modeling, at a 3:1 force ratio, outcomes are bimodal. Either Red or Blue will win big, with equal probability. The stalemate outcome will not occur, even though it would be implied by the uncritical use of deterministic equations. In the C2 context, suppose that two sides had comparable speeds in making decisions. If they were precisely comparable in this respect, and the engagement were decisive, then an actor would want to be well on the favorable side of what appeared naively to be a "breakeven" point.

[17] Some analysts argue that only stochastic modeling is appropriate. Deterministic analysis with suitable exploratory work varying parameter values, however, can avoid the standard pitfalls. Still, for some purposes, stochastic analysis is indeed more insightful and reliable.

refine his choice of axes, write down hypotheses, and test them systematically. Or, of course, he can print off suitably structured data for use in tables or bar charts.

Figure 6. Interface for Exploratory Analysis

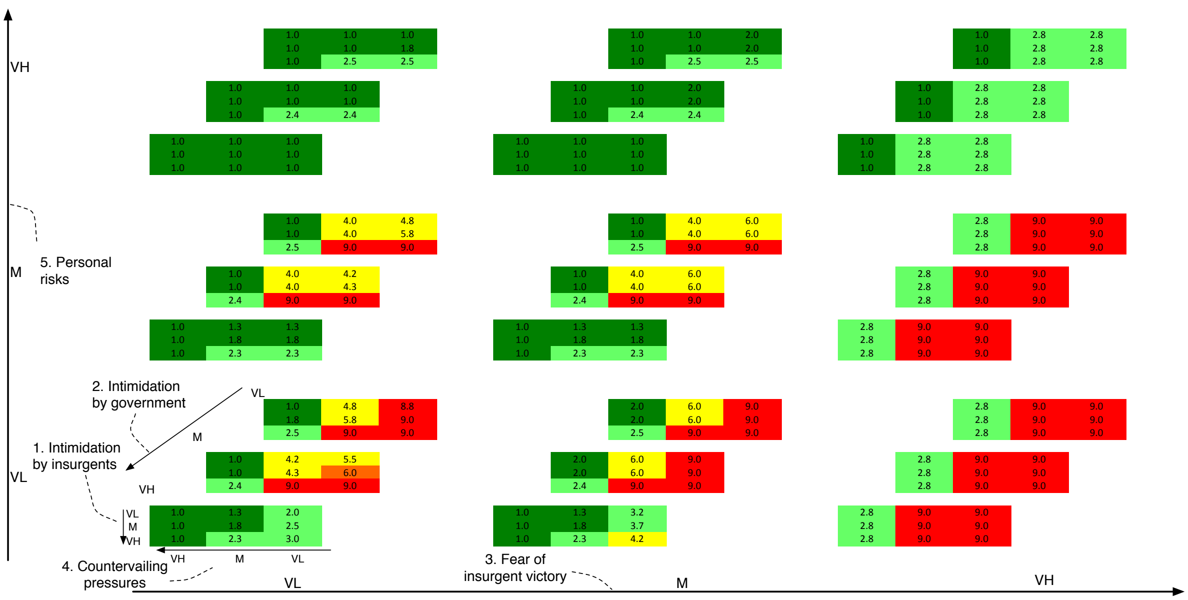


A variant method is to use multidimensional visualizations. Figure 7 is a graphical example from a recent study of public support for terrorism (Davis and O'Mahony, 2013). The result (degree of public support) is represented by color and is shown as a function of five variables.[18] That is, the display shows results over a five-dimensional scenario space. Public support is high (red because it is bad from the perspective of the counterinsurgent) in the bottom right especially, where the public fears the insurgents and where individuals see little personal risk to supporting the insurgency. With four pages and two such displays per page, one can economically summarize results over an eight-dimensional space. This is the modern equivalent, for

[18] The variables are (1) intimidation of the public by insurgents (the y dimension of each such rectangular box), (2) intimidation of the public by the government itself (the diagonal dimension within each group of three rectangular boxes), (3) the public's fear of insurgent victory (X axis), (4) the countervailing pressures on members of the public to *not* support the insurgency (the X dimension of each rectangular box with nine cells), and (5) the personal risks of those in the public (Y axis). These variables were identified in an earlier review of the relevant social-science literature, followed by qualitative model validation on new cases (Davis, Larson, et al., 2012). The numbers in the cells are the outcome values on a 0-10 scale mapped to the colors.

discretized problems, of old-fashioned complex nomograms. Hand-crafted tables can be similarly or more effective.

Figure 7. Illustrative Plot of Outcome Versus Five Independent Variables



Semi-Automated Approach. To many analysts, and probably all computer scientists, such a manual approach is unaesthetic. Why can't the machine find all the interesting information using search methods? Some relevant methods have labels such as cluster analysis, data mining, and artificial intelligence. RAND colleagues use "scenario discovery" to mean identifying the portions of input space that generate good, bad, and indifferent outcomes (finding them may depend on something like "maximum regret") (Lempert, Groves, Popper, and Bankes, 2006; Groves and Lempert, 2007). They often use a clever algorithm called the Patient Rule Induction Method (PRIM) developed at Stanford University. It may report a result such as "80% of the good outcomes occurred when $X > X_0$, $Y<Y_0$, and $Z_0<Z<Z_1$." Such scenario-discovery methods have been used in a number of policy analysis studies, primarily in social-policy subjects relating to climate change, water planning, and rebuilding programs after hurricanes.

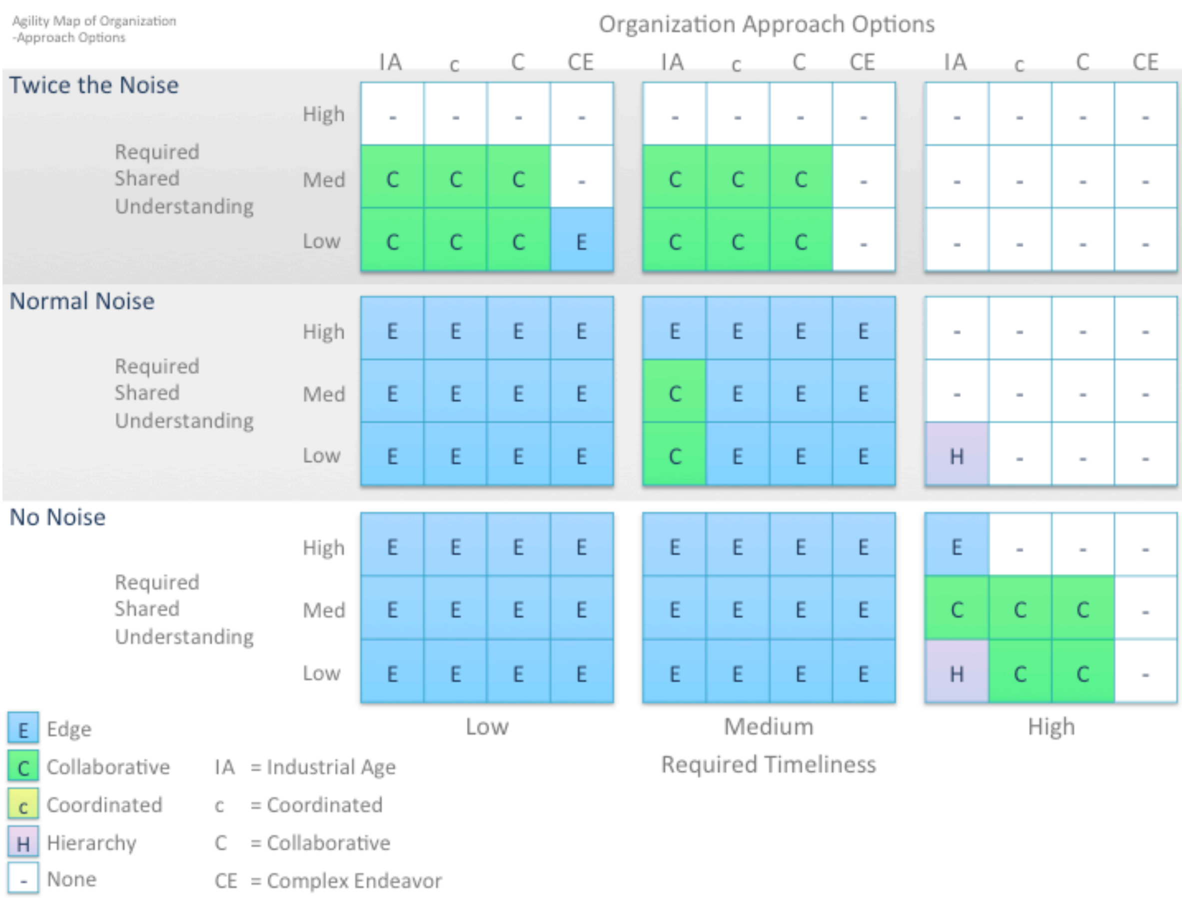
Hybrid Approaches. Analysts are are well advised to use a combination of methods. The manual approach has advantages in fully understanding the problem space, and can be done economically by one or two people without the overhead of complex computer tools. However, the computer-search methods can sometimes discover insights that the analyst misses and, in any case, can do much of the drudge work. When the work benefits from a full suite of tools for design, search, visualization, and post-run analysis, it can be quite powerful.[19] In at least one study, some of us at RAND used a mix of methods to see comparative strengths (Davis, et al., 2007). We saw a good deal of synergy.

[19] RAND's suite of tools for robust decision making (RDM) is of this character (Lempert et al., 2006). It evolved from pioneering work of Steve Bankes in the early 1990s (Bankes, 1993; Bankes, 2002).

An Example from Experiments on C2 Agility

The SAS-085 panel has been experimenting with some analysis methods and displays that are directly analogous to those discussed above. Figure 8 is an "Agility Map" that illustrates a cognitively effective tabular display of exploration over four variables. The letters inside a given table cell indicate which C2 approach came out to be superior in ELICIT experiments within Endeavor space. The particular display shows results for no network damage. Thus, in the particular set of experiments, an "Edge" approach to C2 is superior over quite a large portion of the Endeavor Space.

Figure 8. An Example of an Agility Map

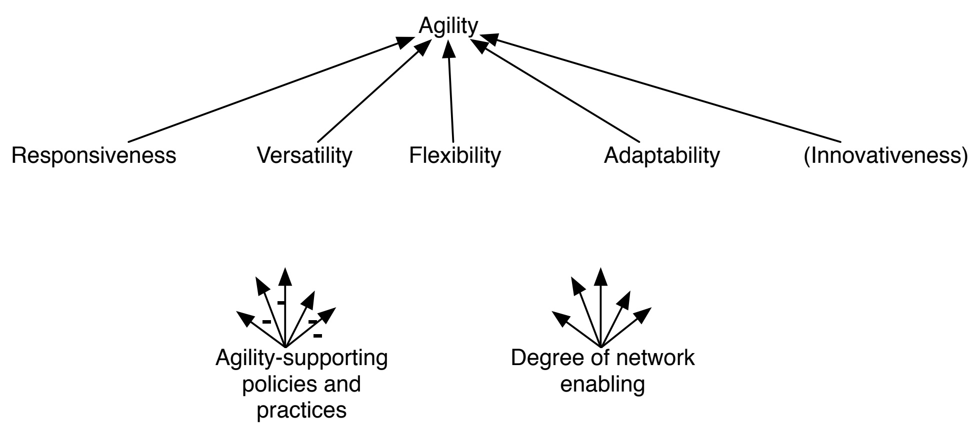


Source: Alberts (2011).

6. AN ATTRIBUTE APPROACH TO ANALYSIS

This paper focuses primarily on an approach to capabilities analysis that uses models and scenarios as discussed earlier. Historically, such analysis has often been the meat and potatoes of defense analysis. However, different approaches are also possible, important, and sometimes better. One is to identify the attributes contributing to what is sought, such as C2 agility, developing metrics for those attributes, and then comparing options in terms of those attributes. Often, such analysis is as insightful as something far more complicated. However, it depends on having identified good attributes, metrics and goals, and ways to display comparisons that do not bias results. Figure 9 is one depiction of the factors that SAS-085 has identified as contributing to C2 agility (in current SAS-85 panel work, the depiction used is rather different, depicting a value-chain perspective). It should be noted that the diagram is not a decomposition. Rather, the various attributes such as responsiveness are variables affecting agility in some not-yet-characterized function. The variables will tend to be correlated in that a C2 system designed for versatility, for example, may be likely to be adaptive as well. As experiments proceed, there may be efforts to theorize about or to infer the functional form of agility's dependence on these variables "empirically." A starting point might be linear regression, but—as discussed in Section 5.2, it might be better to postulate or even enforce a "system" conception in which all of the variables have at least threshold values.

Figure 9. Factors Contributing to C2 Agility



7. IMPEDIMENTS TO PROGRESS AND WAYS TO DEAL WITH THEM

To conclude the paper, some comments on DoD's experience with capabilities-based planning may be useful, so as to anticipate impediments to progress in improving and measuring C2 agility. What follows is the author's list:

1. *Allergies.* Some policymakers and many intermediate-level individuals are wedded to standard-case analysis. They will be allergic to discussions about agility and hedging. The primary coping mechanisms are:

   – Express analysis and recommendations to show hedging as affordable common sense rather than arcane, complex, or a mere nice-to-have.
   – Develop top-level champions who require agility.

2. *Costs.* Hedging costs money in the short run. When budgets are tight, organizations will often drop options and features that they perceive to reduce immediate costs, even if the result will prove *more* costly in the long term. Coping mechanisms include:

   – Embed low-cost hedges into options unobtrusively. This may correspond to conducting low-cost research and development (R&D) with high upside potential, maintaining small groups to maintain expertise, conducting low-cost analytic and simulation-based experiments rather than field experiments, and designing for later adaptations (e.g., leaving "slots" in hardware and encouraging open-architecture designs).

- Demand analysis with life-cycle costs for an uncertain future (i.e., build the expected cost of later adaptations into the analysis).

3. *Analysis By Consensus with Big Models and Data Bases*. Although it might naively be imagined that "analysts" would be naturally supportive of planning for agility, analytic organizations, like most organizations, often prefer consensus work. Further, over the last 25 years they have come increasingly to depend on big models and big data bases, which are designed and tuned for point-case analysis. Coping methods include:
   - Create new, small analytic cells permitted to use only simple models.
   - Task organizations to develop simplified models, including motivated meta models.

4. *Demands for "Requirements."* It is natural for organizations, including military services and commercial contractors, to demand concrete "requirements" when signing up for responsibilities. Doing so avoids open-ended commitments and sharpens obligations in a way permitting a more tightly managed approach to problem solving. In the world of acquisition, it is also a mechanism for increasing profits in that providers can and do impose major cost penalties when their client asks for changes. Coping can include
   - Urging policymakers to insist that "requirements" be expressed in terms of capabilities desired over operational spaces, and that proposed solutions be presented with parametric information about coverage and tradeoffs

5. *Planning Merely to "Wing It."* Many people, including many of the best military officers, pride themselves on adaptation and are quite skeptical about bothering to try anticipating what will be needed. They plan on just "winging it" when the time comes.
   - Insist on doing better by anticipating *classes* of challenge and prepare the agile capabilities to cope.

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