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The System Capability Architecture: Enabling Capability-Based Cost Analysis

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Abstract

Key guidance and instruction such as the DoDI 5000.02 has recently been revised to make mandatory early decision points and analysis such as the Materiel Development Decision (MDD), Milestone A, and Milestone A Analyses of Alternatives (AoA). The push for earlier investment decisions, such as Milestone A, strongly impacts the DoD cost and analysis communities. Although some early decision-making in the past has not been cost-informed, leadership is now requiring cost analysis to inform strategy. Data traditionally used in cost estimation such as quantities, schedules, and acquisition strategy is typically unavailable at Milestone A, making this cost analysis environment particularly challenging.

Capability-based cost analysis was first conceived of to address the problem of data scarcity early in a system's life cycle. It is a technique for producing an estimate using capability data only. The Systems Capability Architecture (SCA) is a binary capability variable set that serves as the foundation for capability-based cost analysis and the Capabilities Knowledge Base (CKB). This paper discusses the SCA in-depth and provides insight into how capability variable definition enables new approaches to cost analysis in data-poor environments. It also articulates SCA relationships with other DoD capability-based management paradigms, and the process and challenges of system capability mapping.

1.0 Introduction / Background

The Department of Defense (DoD)'s decision-making process is changing. The 2006 Quadrennial Defense Review (QDR) report called upon senior departmental leaders to "better integrate the processes that define needed capabilities, identify solutions, and allocate resources to acquire them in order to enable corporate decision-making that cuts across traditional stovepipes". In response to this guidance, DoD leaders have revised key guidance and instruction such as the DoDI 5000.02 to make mandatory early decision points and analysis such as the Materiel Development Decision (MDD), Milestone A, and Milestone A Analyses of Alternatives (AoA).

Prior to Milestone A, system definition is limited. Systems exist as little more than concepts. Pre-Milestone-A systems (or capability sets) are undergoing a period of refinement and exploration that will be continued through Milestone A and beyond. Because the level of definition associated with these systems/solutions is so imprecise, pre-Milestone-A cost analysis has inherent complexities and challenges as analysts and cost estimators are expected to cost programs which neither they nor the interested parties fully understand.

The push for earlier investment decisions strongly impacts the DoD cost and analysis communities. While Pre-Milestone-A decision-making was once a rarity, it is becoming common. Faced with decreasing funds and increasing funding scrutiny, decision-makers must make investment and programmatic choices early. Although some early decision-making in the past has not been cost-informed, leadership is now requiring cost analysis to inform strategy. Although costs are being considered earlier, the data traditionally used in cost estimation such as quantities, schedules, and acquisition strategy is typically unavailable at Milestone A. For this reason, the Pre-Milestone-A cost analysis environment is particularly challenging.

Pre-Milestone-A decision-making often occurs in a data-poor environment. Prior to Milestone A, requirements or desired capabilities are known, but additional information is limited. There is often only general solution information. For cost analysis techniques to be relevant prior to Milestone A, they must take into account all available information. One method of dealing with this data poor environment is to engage in capability-based cost analysis.

Capability-based cost analysis begins with the idea that system capabilities are related to system cost. Once a link between capabilities and cost is established for existent systems, this mapping can be used to estimate the cost of future systems based on their capabilities. If additional information is known or becomes available, it can be used to improve the estimate's accuracy. Capability data joins physical, technical, and performance data as relevant data sources for use in cost estimates.

Capability-based cost analysis and Pre-Milestone-A cost analysis are two distinct concepts. While the necessity of cost analysis during Pre-Milestone A often requires the inclusion of capability-based cost analysis techniques, capability-based analysis has utility after Milestone A has come and gone. Capability-based cost analysis is relevant at all stages of a system's life cycle; it can aid in identification of analogous systems and methodology development whenever applicable and appropriate. To date, the focus of capability-based analysis has been to provide system acquisition costs. However, capability-based cost estimating can also derive costs for maintenance or disposal. Two main advantages of capability-based cost analysis are that it can be done with limited data and that it provides a relatively intuitive output. At times when minimal information is available, capability-based analysis enables the rapid development of estimates that can be reassessed and refined once additional information is known. Since capability-based cost analysis is based on fairly simple concepts, it produces an intuitive end product that is attractive to decision-makers.

2.0 Capabilities Knowledge Base (CKB)

In an effort to meet the challenges of Pre-Milestone-A cost estimating, the Office of the Deputy Assistant Secretary for Cost and Economics (ODASA-CE) in partnership with key support contractor, Technomics, has developed capability-based cost estimating approaches and, in particular, the Capabilities Knowledge Base (CKB). The CKB is a capability-focused analytical tool for cost analysis. It includes a capability-based analysis framework and system capability mappings to cost data [2]. The purpose of the CKB is to aid analysts and decision-makers by supporting early estimate development, and thereby feeding better-informed, more cost-effective decisions. The CKB contains extensive system information from each of the services, allowing it to facilitate joint decision-making. Although the CKB is applicable any time during a program's life cycle, due to its focus on and use of capabilities data, the CKB's primary use is during the Pre-Milestone-A timeframe.

The CKB consists of three primary components: a relational data warehouse, a source data archive, and a cost forecasting toolbox. The data warehouse includes a relational database of systems and their respective capability maps, along with a wealth of additional information such as cost, schedule, and performance data. The data archive includes selected acquisition reports (SAR), defense acquisition executive summary reports (DAES), DoD budget exhibits, and authoritative reference documents. The cost forecasting toolbox currently includes a Jaccard index analogous systems identifier, a capability gap calculator, and a cost per capability calculator [2].

3.0 The System Capabilities Architecture (SCA) and Background

The System Capabilities Architecture (SCA) is the backbone of the CKB. Simply put, it is what links systems to their capability sets for use in a relational database environment for viewing, calculations, and analysis. The relational database of systems and capability maps is stored in the data warehouse portion of the CKB. Through use of the SCA, the CKB enables the study of shared capabilities across groups of systems and analysis of capability redundancies, gaps, costs, and more. One of the key challenges with the development of the SCA is that it required the generation of variables specific enough to meaningfully differentiate among systems and capability sets, but broad enough to be used with the limited information available at Milestone A.

1. Maneuver – Environment	**5. Support**	**8. Sense**	**11. Deploy**
1.1 Ground	5.1 Ground	8.1 Detect	11.1 Self
1.2 Maritime	5.2 Maritime	8.2 Locate	11.2 Ground
1.3 Submerged	5.3 Submerged	8.3 Classify	11.3 Air
1.4 Air	5.4 Air	8.4 Identify	11.4 Water
1.5 Space	5.5 Space	8.5 Track	**12. Train**
2. Control	5.6 Personnel	**9. Protect**	12.1 Training
2.1 Manned	**6. Transport**	9.1 Self	12.2 Leader Development
2.2 Unmanned	6.1 Ground	9.1.1 Stealth	12.3 Enroute Rehearsal (Embedded)
3. Shoot	6.2 Maritime	9.1.2 Armor	**13. Manage Data**
3.1 Line-of-Sight (LOS)	6.3 Submerged	9.1.3 Other	13.1 Store
3.2 Beyond-Line-of-Sight (BLOS)	6.4 Air	9.2 Area Defense (Battlefield)	13.2 Distribute
3.3 Non-Line-of-Sight (NLOS)	6.5 Space	9.3 Regional Defense (Theater)	13.3 Process
4. Explode – Penetrate	6.6 Personnel	9.4 Homeland Defense	13.4 Secure
4.1 Small Effect	6.7 Cargo	9.5 Environment	
4.2 Local Effect	**7. C3I**	**10. Sustain**	
4.3 Large Effect	7.1 Local Area	10.1 Supply	
4.4 Mass Effect	7.2 Wide Area	10.2 Maintain	
	7.3 Area Command and Control	10.2.1 Hardware	
	7.4 Theater Battle Management	10.2.2 Software	
	7.5 Net-Centric	10.3 Reconstitute	

Figure 1: The System Capabilities Architecture

The current version 4.0 of the SCA, as shown in *Figure 1*, was released in March of 2008. It has thirteen (13) main capabilities and seventy-four (74) total capabilities, captured among three tiers. They are Maneuver – Environment (1.0), Control (2.0), Shoot (3.0), Explode -- Penetrate (4.0), Support (5.0), Transport (6.0), C3I (7.0), Sense (8.0), Protect (9.0), Sustain (10.0), Deploy (11.0), Train (12.0), and Manage Data (13.0). These thirteen top tier capabilities have either one or two potential lower levels of refinement, with most having only one potential lower level. For example, under Control (2.0), there are Manned (2.1) and Unmanned (2.2) whereas under Protect (9.0), there are Self (9.1), Area Defense-Battlefield (9.2), Regional Defense-Theater (9.3), Homeland Defense (9.4), and Environment (9.5). Self (9.1) is further broken down into Stealth (9.1.1), Armor (9.1.2), and Other (9.1.3).

When CKB development first began in 2006, ODASA-CE knew that a capabilities variable set (or architecture) would be required in order to establish system-capability relationships. Although the preferred course of action was to use a pre-existing DoD architecture such as the Joint Capability Areas (JCA), it became clear that these did not fit the criteria of the CKB. In order to develop a wide range of capability-based analysis methods including parametric and binary-variable analysis, we needed a specific, distinguishable, well-defined, and analysis-ready architecture. The primary issue in the estimation of ODASA-CE was that the JCA paradigm did not meet the criteria of being specific, distinguishable, and well-defined as to enable capability variable development to support parametric analysis.

Capability Level	SCA WBS	Level 1	Level 2	Level 3	JCA -- Level 1	JCA -- Level 2	JCA -- Level 3
1	1.0	Maneuver – Environment			Force Application	Maneuver	Maneuver to Engage; Insert; Influence; Secure.
2	1.1		Ground		Force Application	Maneuver	Maneuver to Engage; Insert; Influence; Secure.
2	1.2		Maritime		Force Application	Maneuver	Maneuver to Engage; Insert; Influence; Secure.
2	1.3		Submerged		Force Application	Maneuver	Maneuver to Engage; Insert; Influence; Secure.
2	1.4		Air		Force Application	Maneuver	Maneuver to Engage; Insert; Influence; Secure.
2	1.5		Space		Force Application	Maneuver	Maneuver to Engage; Insert; Influence; Secure.
1	2.0	Control			Command and Control	Direct	Task
2	2.1		Manned		Command and Control	Direct	Task
2	2.2		Unmanned		Command and Control	Direct	Task

Figure 2: Subset of System Capabilities Architecture to Joint Capability Areas Mapping

At present, the JCA is under revision to expand and augment the architecture and establish fidelity at the lower tiers. As the JCA, the SCA, and other DoD capability architectures evolve, ODASA-CE hopes to be able to migrate to a common capability paradigm. In the meantime, however, the SCA has been mapped to JCA as shown in *Figure 2* so an analyst can translate between the two, if need be.

Capability	Capability Level	Definition	Example(s)
1. Maneuver – Environment	I	An entity that maneuvers via the ground, water, or air.	Vehicles; ships; and aircraft.
1.1 Ground	II	An entity that maneuvers on the ground.	Ground vehicles and tanks (ex: Joint Light Tactical Vehicle -- JLTV).
1.2 Maritime	II	An entity that maneuvers on the surface of the water.	Ships (ex: DDG 51).
1.3 Submerged	II	An entity that maneuvers below the surface of the water.	Submarines (ex: SSN-774 Virginia NSSN).
1.4 Air	II	An entity that maneuvers within the air of the Earth's atmosphere.	Aircraft; helicopters; and unmanned aerial vehicles (UAVs). Ex: C-130J Hercules.
1.5 Space	II	An entity that maneuvers beyond the air of the Earth's atmosphere (i.e. space).	Shuttles; rockets; and other spacecraft (ex: Titan IV, Expendable Launch Vehicle -- ELV).
2. Control	I	An entity of any type that is controlled.	Ground vehicles; ships; UAVs; and UGVs.
2.1 Manned	II	An entity of any type that is manned or controlled by a person within the entity.	Any manned water, ground, or air vehicle (ex: Stryker).
2.2 Unmanned	II	An entity of any type that is not controlled by a person within the entity.	Unmanned aerial vehicles (UAVs) or any unmanned ground or water entity (ex: VTUAV -- Fire Scout).

Figure 3: Subset of Capability Architecture with Definitions and Examples

Due to the numerous potential interpretations of the individual capabilities, a SCA dictionary accompanies the SCA. A portion of the SCA dictionary is shown in *Figure 3*. Each capability within the SCA is defined in the SCA dictionary, and changes to the SCA have an immediate and clear corresponding change in the SCA dictionary. Furthermore, detailed capability mapping procedures have been established in order to make the mapping process transparent and repeatable. More detail into the capability assignment process is provided in **Section 4.0**.

The SCA enables analyst use of relevant data for capability-based cost analysis. In keeping with this intent, the SCA has been updated as necessary. The SCA is a fluid entity that continues to evolve based on improvement of available information and subject matter expert/peer review. As new systems are added to the CKB and knowledge of the acquired capability inventory grows, the SCA has and will continue to change. Input from the user community is also vital in order to help craft the most useful variable structure (and analysis tools) possible.

4.0 The Capabilities Assignment Process

Although an inherently involved process, the task of assigning capabilities to a system is kept as simple and intuitive as possible. System capabilities are binary variables; in other words, a system will either possess or not possess a given capability. In order to use the SCA, an analyst only has to determine whether or not the system under consideration has a particular capability or capabilities; further information is not required.

When developing capability maps for systems residing within the CKB or for systems being analyzed, it is imperative to involve platform subject matter experts to the fullest extent possible. Although situations where analysis time is limited (and therefore collaboration time is limited) certainly arise, it is suboptimal. It is also important to define a system boundary as well as possible --- in other words, to clearly designate what is included and excluded from a system (or capability set). One key consideration when determining system boundary is to consider what portions of the system were developed and procured with its allocated funding. For instance, government-furnished equipment may or may not be included in the system boundary, according to how the system or program was structured and funded.

All applicable capabilities are included, not just the major ones. For example, if a key characteristic of a system is its ability to shoot and the system also senses threats, both capabilities are included in the assigned capability set. When assigning capabilities to a program that is an upgrade to an existing system, only those capabilities specifically addressed by the upgrade are included. For example, if the upgrade in question deals solely with a fixed wing aircraft's fire control systems, the capability set for this acquisition would capture only fire control-related capabilities. The capability of maneuvering via air would only be included if the upgrade also addressed the flight systems. These examples demonstrate that analyst judgment and expertise is a key component of developing and using the SCA (and CKB) and engaging in capability-based cost analysis.

Capability assignment typically begins at the top tier level. The user would evaluate the thirteen main capabilities to determine their applicability to the capability set/system under consideration. If there is not enough knowledge of the system to make a further determination of its capabilities by using the second level of the architecture, the user can stop after assigning level one capabilities and still be able to use the CKB's cost forecasting tools. However, if further information is known, the second level can be evaluated just as the first level was evaluated. If the capability has a third level of definition and enough program information is known, the third level can be evaluated in the same manner as the other levels.

Detailed capability mapping procedures have been developed to accompany the SCA. These are necessary in order to standardize and expedite the mapping process, making it transparent and repeatable. It is desired that a CKB system user will easily be able to trace how a system was mapped to its capability set, or be able to spot any errors or anomalies quickly. Capability mapping is an iterative process subject to continuous improvement efforts by its community of interest.

5.0 The Capability to Performance Data Progression

Capability-based cost analysis was first conceived of to address the problem of data scarcity early in a system's life cycle. It is a technique for producing an estimate using capability data only. However, such an estimate inherently has a high level of uncertainty associated with it. Capabilities alone are useful, but if performance or technical data is available, it behooves an analyst to make the best possible use of the additional information.

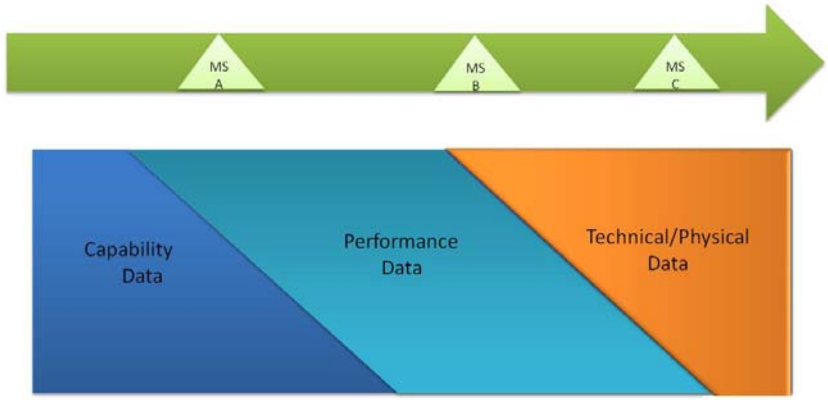

Figure 4: Cost Analysis Data Progression

As shown in *Figure 4*, the types of data suitable for analysis at various points in the acquisition life cycle can be thought of as being on a continuum. Pre-Milestone A and at Milestone A, capability data is almost certainly available to support cost analysis, and it is likely that there is at least some performance data available, as well. As a concept or system matures, the available and suitable data set to support analysis transitions from capability data to performance data and eventually to mostly technical and/or physical data. As outlined in previous sections, the capability variable set formalized by the SCA is what enables cost analysis based on capability data at early decision points.

The CKB facilitates the combined usage of capabilities, performance, technical, and physical data. For example, the capability of ground-based movement can be used with or without such associated performance data as average miles per hour or maximum range; a shooting capability can be used with or without information on the system's accuracy. While the addition of performance data can increase the accuracy of a capability-based cost estimate, such information is not mandatory.

A recent capability-based cost estimate developed at ODASA-CE for the Joint Effects Targeting System (JETS) used not only capability data, but also performance data [1]. The performance data was not only available for analysis, but also withstood subject matter expert scrutiny. One matter for concern Pre-Milestone A is that available performance and/or technical data may reflect requirements, and may not accurately represent the actual end state of the system, due to technical impediments or overly optimistic analysis. This is an issue for which an analyst must always be watchful and attuned, if Pre-Milestone-A analysis is to be accurate and able to set up a system/program for acquisition life cycle stability.

6.0 Summary and Conclusions

Change has come to DoD in the form of increased and scrutinized Pre-Milestone-A and Milestone A cost analysis. As articulated in previous sections, capability-based cost analysis is a way of thinking about cost methodology that is designed to cope with the data-poor environment that exists pre-Milestone A. However, it is self-evident that capability-based cost analysis is not limited to the pre-Milestone-A timeframe (and that pre-Milestone-A cost analysis should not limit itself to capability-based cost analysis).

The SCA is the foundation of capability-based cost analysis and the CKB due to the fact that it establishes, defines, and standardizes capability data variables for its use. Moreover, by definition, it attempts to articulate the breadth of the DoD capability set. Although the SCA is independent from DoD capability-based management paradigms such as the JCA, the Universal Joint Task List (UJTL), and the Functional Capability Boards (FCB), it leverages these and maps directly to both the JCA and the FCB. It is not inconceivable that the JCA and SCA may one day converge, since the current JCA revisions are evolving the capability areas to entities more suitable for binary variable analysis. In the meantime, however, the SCA fills this role for the cost analyst. To this end, it is imperative that the cost analysis community be active participants, and provide input into ways to improve and enhance capability-based cost analysis and the SCA.

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