

**Capabilities-Based Cost Estimating:
Capabilities Knowledge Base (CKB) Analysis Tools and
Applications**

Prepared by:

Chadd Sibert

Office of the Deputy Assistant Secretary of the Army for Cost and Economics
(ODASA-CE)

Arlington, VA 22202, United States

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Abstract

Cost analysts in today's environment often find themselves being asked to analyze solutions identified to fill capability gaps that are poorly defined. Often, only a requirement or desired capability set is known. Is this sufficient information to produce a cost estimate? Are there any tools available to support this effort? If so, how would one utilize them?

This work submits that the Capabilities Knowledge Base (CKB) can be used to support this need, and it suggests that the CKB can be used to support the development of early cost estimates for proposed materiel or non-materiel solutions, based on that solution's capability set. By using the tools, relationships, and data from the CKB, a cost estimate to support early investment decision-making may be developed. Both the data and the tools contained within the CKB are explored in this paper.

I. Capability-Based Cost Estimating

Capability-based cost estimating is a relatively new concept. It first materialized in response to the need for cost estimates to be provided to decision-makers in a more timely fashion and much earlier in the acquisition life cycle. Capability-based cost estimating relies on using the capabilities of current systems and their associated costs to provide early cost estimates for capability-filling solutions to decision-makers.

Prior to the evolution of capability-based cost estimating, cost analysts traditionally relied on physical, technical, and performance-based data. For example, the actual weight and cost of an existing system could be used to form an analogy to estimate the cost of a future weapon system.

Cost analysts, however, often find themselves being asked to analyze solutions identified to fill capability gaps that are poorly defined. Available information can range from a list of desired capabilities to (in some cases) high-level materiel solution descriptions or limited design specifications. Capability-based cost estimating allows for the analysis of a material or non-material solution without requiring insight into the physical, technical, or performance characteristics of the solution¹.

II. Past Successes

The Early Cost Team at ODASA-CE has successfully utilized capability-based cost estimating techniques to generate cost estimates for several systems to date. This technique has been successfully utilized to generate not only reliable Pre-Milestone-A estimates (examples include the Joint Light Tactical Vehicle and the Joint Effects Targeting System²), but also to provide cost support throughout the entire acquisition life cycle. Capability-based cost estimating has also been found to be quite helpful when performing additional studies such as Analysis of Alternatives (AoA) and system comparisons. Further examples of the potential use of capability-based cost estimating are provided later in this work.

¹ M. Roper, 'Capabilities-Based Costing: Approaches to Pre-Milestone-A Cost Estimating', 2007.

² D. Hull, 'Capability Costing Methods and Challenges', 2009.

III. The Capabilities Knowledge Base (CKB)

The Capabilities Knowledge Base (CKB) was designed and developed by the Early Cost Team to facilitate the use of capability-based cost estimating. The CKB provides the high-level system capability, cost, and performance data required to produce cost forecasts within stricter timelines. The CKB is fundamentally composed of three major elements: the Data Warehouse, the Data Archive, and Analysis Tools.

Data Warehouse

The data warehouse currently contains the capability mappings, cost / budgetary data, and technical characteristics for over 200 existing Department of Defense (DoD) military systems. Each system within the CKB is mapped to a standard capability architecture, referred to as the System Capability Architecture (SCA), which was also developed by the ODASA-CE Early Cost Team³. A binary indicator is used for each of the 74 distinct capabilities to identify whether a system has the specified capability (i.e. '1') or does not (i.e. '0'). This binary indicator simply indicates that a system does or does not possess a specified capability. It does not address the magnitude of the system performance for that capability. The SCA is organized as a three-tiered hierarchical architecture. Each capability is assigned a level that refers to its relative position within the capability hierarchy. A Level I capability represents a 'parent' whereas a Level II capability represents a 'child' of a Level I capability. *Figure 1* below illustrates a small subset of the current SCA.

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 1: Subset of System Capability Architecture (SCA).

The data warehouse also contains not only the most recent, but also all historical cost / budgetary data for each existing system in the Department of Defense inventory. Cost data for the following acquisition phases is included for each system: Research Development Test and Evaluation (RDT&E), Procurement, Military Construction (MILCON), as well as Operations and Maintenance (O&M). In addition to this cost data, the warehouse also contains numerous descriptive programmatic fields. For example, scheduling data, which documents the progression of the system through the acquisition life cycle, is also included for each system. *Figure 2* details a subset of the data fields contained within the data warehouse.

³ K. McCormack & M. Roper, 'System Capability Architecture: Enabling Capability-Based Cost Analysis', 2009.

Acquisition Category (ACAT)	Milestone Dates
Functional Capability Area (FCA)	O&M BY & TY Costs
Initial Operational Capability (IOC)	Procurement BY & TY Costs
Lead Organization	RDT&E BY & TY Costs
MILCON BY & TY Costs	Service
MILHDBK881A System Type	System Name
Military Designation	Unit Costs (APUC & PAUC)

Figure 2: Subset of Data Warehouse Fields.

Finally, pertinent technical characteristics are also included in the data warehouse. Characteristics such as fuel efficiency, range, and weight are just a few examples of those included. These characteristics are especially beneficial when conducting system comparisons as they provide insight into the performance of individual systems in comparison to each other. This data is also especially useful when conducting statistical analyses.

Data Archive

The second major element of the CKB is the data archive. This is an archive of all of the source documents for the data stored within the data warehouse. This feature allows the user to not only be able to reference the source document for a given piece of information, but to also view it. All of the data within the archive is stored in Adobe Portable Document Format (PDF) files. This format maintains the integrity of the original source document while also allowing for easy viewing by the user.

Analysis Tools

The third and final key element of the CKB is a robust set of analysis tools to be utilized by the end-user. This set of analysis tools is naturally divided into two major parts: Data Navigation and Analytical Tools.

The data navigation tools allow the user to efficiently search for and locate information within the vast data set contained in the data warehouse as well as the data archive. This tool provides the end-user with data on which they could then perform analysis as they wish. The Analytical Tools, however, perform a specific analysis algorithm based on the end-user’s input. There are currently three analytical tools available within the CKB. Each of these analytical tools is capability-based, and thus will be extremely beneficial when completing any capability-based analyses.

Each of the analysis tools contained within the CKB will be explored in further detail in subsequent portions of this document. We intend to demonstrate that, not only does the CKB support early or Pre-Milestone-A costing, but it also can support post-Milestone-A costing. Specific examples of how the CKB can be used for all phases of the acquisition life cycle, as well as in support of parametric and analogy-based cost estimating; will be provided later in this document.

IV. The CKB Analysis Tools

Data Navigation

The user currently has three means of searching the data within the CKB. The first method is to search the contents of the data warehouse and data archive, respectively, for a user-provided keyword. This search mechanism allows the end-user to efficiently search the entire contents of the CKB for pertinent information, while requiring only a single input. This feature can be extremely valuable when trying to search the CKB for information related to a specific program or when refining a previous search.

The second navigation method available to the end-user is data filtering. Data filtering is currently available for the top nine most searched upon data fields within the CKB. Drop-down list boxes are provided for each of these key data fields. The end-user may select any combination of these nine data fields for a given search.

An added feature of the CKB Data Navigation toolset is that the two aforementioned navigation methods may be used in conjunction, providing a third search mechanism. This provides the end-user with a powerful, precise, and efficient search mechanism for the extensive array of cost, schedule, technical, and programmatic data housed within the CKB. In total, ten search criteria may be specified on a given query, providing results that are highly correlated to the search criteria. **Figure 3** below provides a visual display of the data navigation user-input screen.

The screenshot shows a web interface for data navigation. On the left, there is a list of search criteria: Program Type, ODASA-CE Type, Service, Acquisition Type, Acquisition Category, Cost Type, Data Source, Attribute Source, Capability Level, and Search String. Each criterion is followed by a dropdown menu. The dropdown for 'Data Source' is currently open, showing options: All, SAR, and DAES. To the right of the dropdowns are two buttons: a green 'SEARCH' button and a red 'RESET' button. At the bottom, there is a text input field labeled 'Search For This String'.

Figure 3: Data Navigation Input Screen.

The data navigation tools allow for a high degree of flexibility. Either a very basic or a very specific search can be conducted based on the amount of search criteria provided. These features make the data navigation tool very attractive for numerous applications. One such key application is the study of cost growth. The CKB has been used to study both the cost growth among specific systems as well as across entire system types, and services. As previously stated, the CKB Data Warehouse contains not only the most recent cost / budgetary data, but also historical data. Thus, the end-user would quickly be able to obtain the historical cost data for the system(s) of interest by using the data navigation tool. The cost growth analysis can then be completed using the retrieved data.

A capability comparison analysis is yet another application for this toolset. This analysis is often conducted as part of an AoA, for example. The capability mappings for each system can be

retrieved from the CKB using the data-filtering option. These mappings can then be compared and analyzed along with their cost data.

Analytical Tools

There are three analytical tools currently available within the CKB: Analogous Systems Identifier; Capability Gap Calculator; and the Cost per Capability Calculator. Each of these three respective tools is capability-based and has unique benefits to offer to the analyst.

The Analogous Systems tool identifies and provides the user with the list of the most similar or analogous existing systems to a set of capabilities that were specified. This set of capabilities or system of interest could represent a potential future system or an existing one. This tool utilizes the Jaccard indexing and weighting method to identify analogous systems. The Jaccard index result can range from zero to one. The strength of using this method is that it takes into account capability matches as well as disparities.

There are three input criteria that the user may specify. The first potential input criterion is to specify the capabilities of the SCA in which they are interested. For example, if the theoretical capability set has five specific capabilities, then they should be sure to select these same five capabilities in the input screen. Next, the user may identify a minimum Jaccard value to include in the results. Specifying this value restricts the output to only those existing systems that have a Jaccard value greater than or equal to that of the minimum value specified. Finally, the end-user may further constrain the output by specifying a system type of interest.

The analogous systems output is presented graphically as a series of stacked bars. Each system that is determined to be analogous and has a Jaccard index value greater than or equal to the minimum specified value is included in the results. **Figure 4** provides a visual display of this output. Please note that this output is for example purposes only and is based on notional data. Each individual bar within a stack represents a specific capability. If the bar appears above the x-axis on the chart, then both the analogous system and the system of interest have that same capability. Conversely, if the bar appears below this axis, then the analogous system possesses a capability that the system of interest does not. Also, a one unit tall bar for an analogous system represents a direct capability match for all three levels of the SCA to the system of interest. A half-unit tall bar represents a capability match at Level I of the SCA but a mismatch at Level II and / or III, respectively. In **Figure 4**, the capability profile of the 'System of Interest' is the left-most stacked bar. The existing system that has been determined to be the most analogous to the system of interest, 'Analogous System 1', is represented by the stacked bar to the immediate right of the system of interest. While 'Analogous System 1' largely possesses the same capabilities as the system of interest, there are some differences. For example, 'Analogous System 1' possesses the Capability '10 Sustain' while the system of interest does not. Also, even though both of the systems possess the Level I capability of '5 Support' and '8 Sense', respectively, they do not possess the same Level II and III capabilities as evidenced by the half-unit tall bars for these two capabilities.

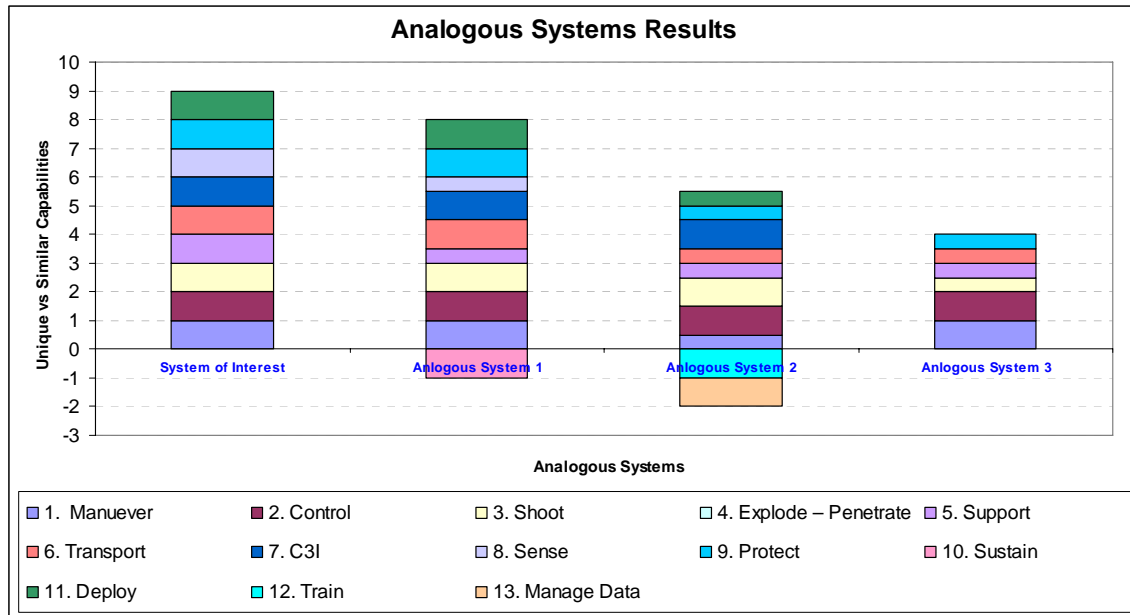


Figure 4: Analogous Systems Tool Sample Results. *

** Please note that these results are for example only and are based on notional data.*

This tool enhances the efficiency of the cost analyst developing an estimate. With a maximum of three inputs, the end-user will have a list of systems that are similar to their system of interest based on the respective capability sets. The cost and technical data for each of these analogous systems could then be retrieved from the CKB. At this point, the analyst has much of the information that they would need to do an estimate by analogy, for example. Moreover, the analyst could use the retrieved systems along with their pertinent information and perform statistical analysis to develop a cost estimating relationship (CER). These are just two of many applications for which the Analogous Systems tool can be beneficial.

The Capability Gap Calculator is another analytical tool contained within the CKB. This tool identifies and provides a summary of the capability gaps for a given set of systems using the vast data set stored within the data warehouse. This tool also illustrates which capability gaps a potential system would mitigate. A capability gap is defined as a capability or capabilities that the existing inventory of systems does not possess. If a potential future system possesses these absent capabilities, then, by definition, it would mitigate the capability gaps.

There are two input criteria that may be specified for this tool. The first potential input criterion is to specify the capabilities or system of interest. The capabilities of interest typically would correspond to those of a new proposed system (or system of systems). The second input criterion is the option to further limit the results set by specifying a system type of interest.

The Capability Gap Calculator output is graphically presented as a series of clustered columns. Both the quantity of existing systems that possess the capability and the capabilities of interest are plotted for each of the thirteen Level I or 'parent' capabilities. **Figure 5** provides a visual display of this output. Please note that this output is for example purposes only and is based on notional data. In this figure, the 'Aircraft Systems' columns represent the quantity of the

existing systems within the aircraft system type that have that particular capability. As can be seen in the figure below, (quantity) eight aircraft systems have the ‘1.0 Maneuver – Environment’ capability. However, this figure also shows that there are several capability gaps within the current ‘Aircraft Systems’ inventory. For example, none of the existing systems possess the ‘12.0 Train’ capability. The ‘Capabilities Specified’ columns directly correspond to the capabilities of interest that were specified by the user. A capability gap would be mitigated by the proposed capability set whenever there is a value for the ‘Capabilities Specified’ column for a given capability and there is not any value for the ‘Aircraft Systems’ column. An example of this is the capability ‘13.0 Manage Data’ in *Figure 5* below.

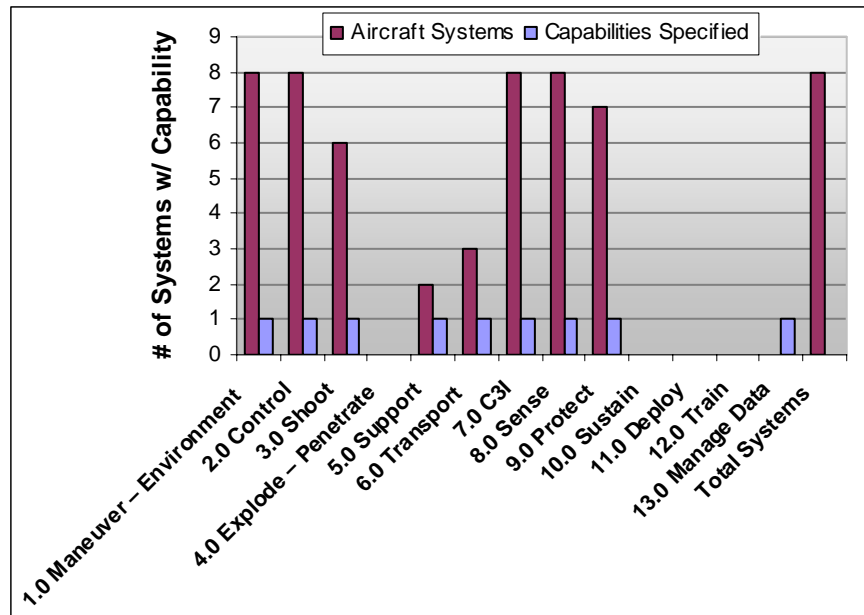


Figure 5: Capability Gap Indicator Sample Results. *

** Please note that these results are for example only and are based on notional data.*

This tool will not only aid the cost analyst, but also the high-level decision-maker. The identification and mitigation of capability gaps is a mission-critical exercise that is typically undertaken early in the acquisition life cycle. This tool not only provides a snapshot of the capability gaps within the existing system inventory, but also provides a view of what capability gaps would and would not be mitigated by a potential future system.

The third and final analytical tool contained within the CKB is the Capability Cost Calculator. This is an extremely powerful tool that is currently still being refined. The Capability Cost Calculator in its current form can provide an early cost estimate based solely on a few inputs.

The user simply inputs the capabilities or system of interest. A system type may also be specified to further limit the output. The tool then determines the most analogous systems as described earlier in the Analogous Systems Tool discussion and retrieves the historical actual costs for these systems. Regression analysis is then performed on the set of analogous systems along with the system of interest. The costs can then be displayed in two fashions. They may be

shown as either a cost per capability or summed to provide an early cost estimate for the system of interest.

The potential use and impact of this tool is great. An early cost estimate for a system could be provided within a matter of seconds, assuming that the capability set has been defined. This tool would be helpful when completing an AoA, trade-off studies, as well as pre- and post-Milestone-A estimates. However, it is important to reiterate that this tool is still being refined. Also, it is in not meant to be a 'black box' solution for the end-user where they would be presented with a solution with minimal explanation or insight into how that solution was derived. It is very important that the analyst fully understand both the data set and methodology used.

V. Conclusions and Future Pursuits

Capability-based cost estimating is a method that has been successfully utilized to provide enhanced cost information early in the acquisition life cycle to decision-makers to enable better-informed decisions. The Capabilities Knowledge Base (CKB) is intended to be an empowering tool for analysts performing capability-based cost estimating. The CKB can be used by both the cost/capabilities analyst and by high-level decision makers. It can support the development of an early cost estimate as well as support many other analyses as described at length in this paper.

However, there still is much to be done in regards to enhancing capability-based cost estimating and the use of the CKB. One of the most critical next steps is to ensure the availability of the CKB across the cost analyst community. This is underway, and the CKB Web Portal is currently nearing its launch in 2009. Also, refinement of existing analysis tools and development of new tools is critical. While it is clear that capability-based cost estimating and the CKB can help the cost analyst meet some of today's challenges, there is still significant opportunity for further progress.

POC: Chadd Sibert
Operations Research Analyst, ODASA-CE
chadd.sibert@hqda.army.mil
(703) 601-4125
DSN 329-4125

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