Designing a Conceptual Framework for Estimation and Analysis of Total Ownership Cost

Abstract

In recent years, the push for greater efficiency and productivity in Defense spending has yielded an increased focus on affordability analysis. Understanding and estimating Total Ownership Costs (TOC) is key in assessing affordability, and the cost community must adapt to support TOC estimation.

This paper discusses the development of a conceptual framework for estimating TOC in support of a broader audience, from the acquisition community to program managers and even as a decision support tool for entities such as Congress, DoD Financial / budgetary community, and G-8 Program Analysis & Evaluation. In developing this framework, we examined cost element structures and relevant organizational factors of the Army, Navy, NASA, UK MoD and others. We looked at the different use cases associated with TOC estimates, and studied the various roles and personas involved.

This examination provided useful insights, including how various structures (cost element structure, organizational structure, and work breakdown structure) combine to influence the execution of a TOC estimate. Our analysis led us to the development of a generic TOC estimating methodology. The approach is complete, can be tailored for multiple use cases, maps well to standard cost breakdown structures, and aligns well with current acquisition-specific estimating practices.

Introduction and Background

The requirement for affordability assessment via TOC analysis is receiving renewed emphasis in the Department of Defense. Ashton Carter's memorandum "Mandate for Restoring Affordability and Productivity in Defense Spending" [1] is intended to "make affordability a requirement," and Total Ownership Cost is key in assessing affordability. DoD Directive 5000.01 E1.1.4 Cost and Affordability states, "All participants… shall view cost as an independent variable, and … shall plan programs based on realistic projections of the dollars and manpower likely to be available in future years. To the greatest extent possible, the Milestone Decision Authority (MDA) shall identify the total costs of ownership, and at a minimum, the major drivers of total ownership costs" [2]. Clearly, TOC estimation and analysis is a major concern in the DoD.

To address this, our goal was to design a conceptual framework to enable TOC estimation and analysis for the Aerospace and Defense (A&D) community. The A&D community is large, spanning many government and private organizations. A requirement of this framework is to support people from these many points of view. This broad audience includes stakeholders from the acquisition community, cost estimators and program managers up through the highest levels, such as Congress, DoD financial/budgetary community, and G-8 Program Analysis & Evaluation.

We began our research with an estimation framework that is well-designed for estimating within the acquisition community. In defining the scope of our expansion to TOC, we examined many definitions. In general, TOC is defined as an "Estimate of all direct and indirect costs associated with an asset or acquisition over its entire life cycle" [3]. From the DoD's perspective, "DoD TOC is the sum of all financial resources necessary to organize, equip, train, sustain, and operate military forces sufficient to meet national goals in compliance with all laws, all policies applicable to DoD, all standards in effect for readiness, safety, and quality of life, and all other official measures of performance for DoD and its Components. DoD TOC is comprised of costs to research, develop, acquire, own, operate, and dispose of weapon and support systems, other equipment and real property, the costs to recruit, train, retain, separate and otherwise support military and civilian personnel, and all other costs of business operations of the DoD" [4].

Research Method

1. Use Case and Stakeholder Persona Analysis

Our research began by determining how this framework will be used from a variety of perspectives. After an extensive literature search, we found that the there are three main use cases associated with a TOC analysis framework within the A&D community:

- **Baseline TOC Estimate**: To establish the basis of the Total Ownership Cost of a proposed program, project, or system for use in contract proposals, trade studies, budget development, and program execution / tracking.
- **Affordability Analysis**: To compare the Total Ownership Costs of alternative solutions to achieve a minimum acceptable mission / operational capability at the least cost.
- **CAIV Engineering Trade-Off**: To systematically explore the reduction of Total Ownership Costs of Major Weapon or Information Systems by estimating costs associated with changes to the system design.

The use of these three major use cases helped guide our research, as it helps define how the framework will be used. First, we examined the persona of every stakeholder we could identify, and then examined the role each persona plays in terms of each use case. Figure 1 shows an example characterization of a Lead System Engineer stakeholder:

Title	Roles and Responsibilities	Use Case Tasks
Lead System Engineer	Responsible for the development of the physical architecture of the systems to be costed. Also responsible for the development and documentation of system requirements	1. Analyze requirements 2. Develop PBS in conjunction with technical leads 3. Develop WBS in coordination with program management 4. Oversee development of system physical architecture 5. Provide technical input to program schedule 6. Provide input to cost estimators for development of system costs 7. Oversee design to cost analysis

Table 1: Example Persona Analysis - Lead System Engineer

A similar analysis was done for all the various stakeholders, including cost estimators, operations research analysts, software engineers, contract program managers, government program managers, congressional staffers, G-8 PA&E analysts, etc. With the personas clearly identified, we then mapped out the major steps of each use case.

Each step in the use case was broken down in terms of the personas involved, inputs, process, and outputs. For example, let's look at Step 1 of a building a Baseline TOC Estimate: "Construct a Work Breakdown Structure (WBS)."

Involved Personas	Input	Process	Output
Cost Estimator, Lead System Engineer	Knowledge of: -Physical Architecture -Matrix Program Functions -O&S structure in context of organization	-Model physical architecture -Add applicable program functions to WBS (Integration, SE, PM, etc.) - Add applicable O&S cost elements to WBS.	Complete WBS modeled in the TruePlanning Estimation Framework.

Table 2: Example - Use Case Step Breakdown for Step 1: Construct Work Breakdown Structure

With this information, we can identify what features and functions the Estimation Framework must provide. From this first step, the framework needs to support the construction of a WBS, from components representing physical architecture, matrix program functions, and O&S organizational structures. This analysis of a single step was repeated for every remaining step in the Baseline TOC Estimate Use Case, including Construct WBS, Assess Cost Model Drivers, Calculate Cost, Validate Model, and Map to Reporting Structure. Then, this complete analysis was done for the other 2 use cases, CAIV Engineering Trade-Off and Affordability Analysis.

The result of this exercise was a complete list of functions the framework will support, and a list of features required to support them. This complete feature list is a major part of the conceptual design of our TOC estimation framework, however there is still a need to fully understand the structure and presentation of the output. The next section will focus on our design of the output and reporting structure of the framework.

2. Output/Reporting Structure Analysis

Our examination of the Estimation Framework features and the interested stakeholders led us to some insights on how to best structure the output reports. Many of these stakeholders have to report findings in standardized formats. These formats break down the estimate in a way that aids their decision-making. We're able to classify the common formats into 3 types: a Work Breakdown Structure (WBS), a Cost Breakdown Structure (CBS), and an Organization Breakdown Structure (OBS).

- **Work Breakdown Structure (WBS):** A deliverable-oriented breakdown of a project. Generally broken down into systems, subsystems, components, and work packages. Example: Mil-Std-881C [5]

- **Cost Breakdown Structure (CBS):** A breakdown of a project into cost categories. These categories usually represent budget appropriations.

- **Organization Breakdown Structure (OBS):** A breakdown of a project into organizational "groups." The OBS shows each organization involved in the project and how they distribute project responsibilities among subgroups. Example organizations are Congress, the Program Executive Office (PEO) for the project, and Prime/Sub-contractors. The organizations can be further broken down by sites, departments, teams, etc.

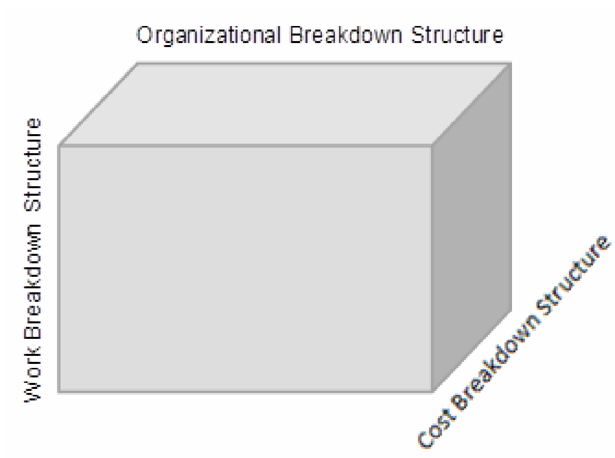

Figure 1: WBS-CBS-OBS Cube

These structures are frequently used by various stakeholders of a project. The WBS aids in defining scope, developing project plans, and doing analysis of alternatives. The OBS clearly defines the different groups involved in the project, and how they relate to one another in the context of the project. The CBS is useful for planning, budgeting and tracking execution. Estimates made in our framework should be organized to match each point of view to aid these decision-makers and enable them to do their job. Structuring a cost estimate such that it can be mapped to a WBS, OBS, and CBS is therefore crucial. Upon studying the relationship between these structures, a picture of a cube emerges, which yields more useful insights.

Let's take the example of an Aircraft project. An estimator performing a CAIV engineering trade-off is comparing two different airframe alternatives, both of which deliver the required capability, to see which yields the lowest total ownership cost.

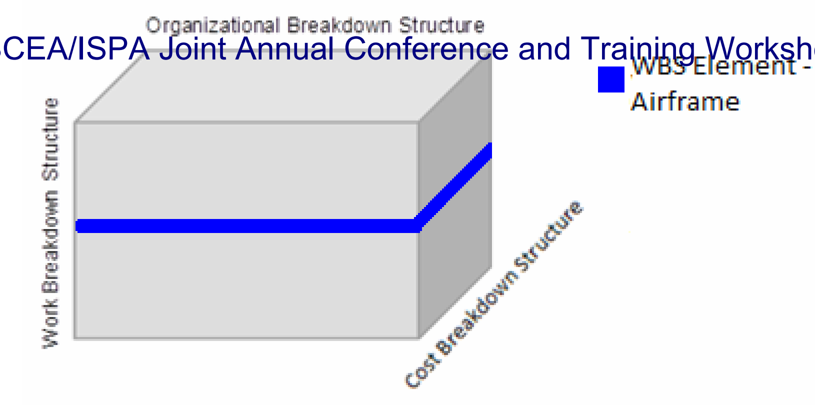

Figure 2: WBS Slice – Airframe

The slice of the cube shown in Figure 2, representing the WBS "Airframe" element, allows you to see all information specific to the Airframe. At the CBS intersection, you can analyze cost estimates and funding for each piece of the airframe. At the OBS intersection, you can see which groups are performing Airframe-specific work. You can replace this element in our framework with an alternative design, and run the cost model again as a quick-and-easy method for CAIV Engineering Trade-Offs.

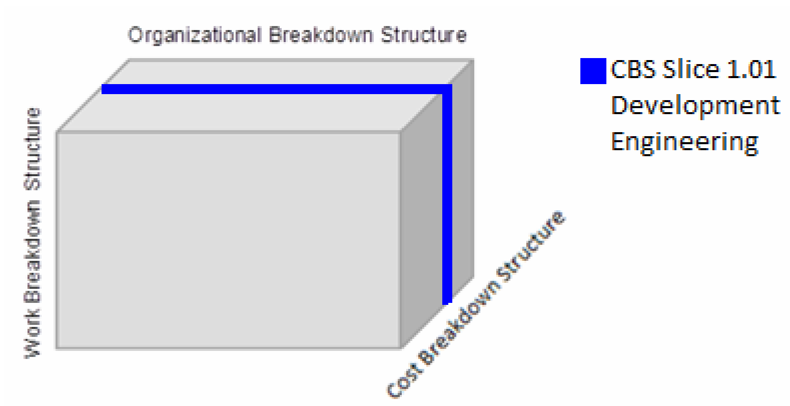

Figure 3: CBS Slice – Development Engineering

Now, let's take a CBS slice of the cube in Figure 3. This slice represents "Development Engineering" cost category. Development engineering is performed by multiple OBS groups, and applies to a variety of aircraft components (WBS elements). Since this slice represents its own budget category, you can see how this budget breaks down across these organizations and components. The ability to break down a project this way aids in planning, allocating budgets, and tracking execution. Any cost category can be viewed, making this a useful reporting structure for project planners, managers, budget analysts and more.

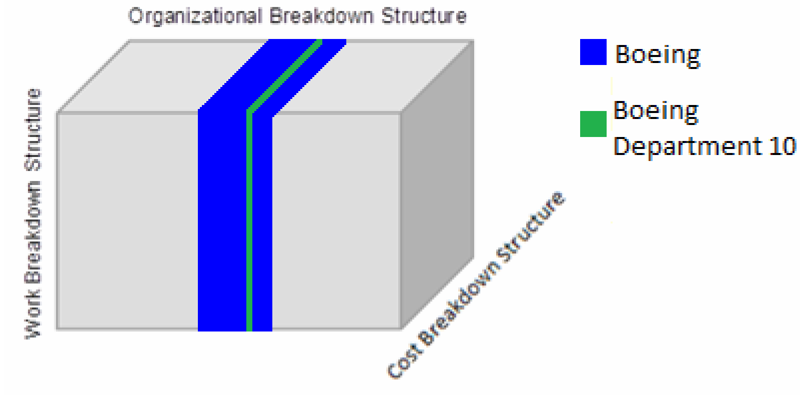

Figure 4: OBS Slice – Boeing

Finally, the OBS slice represents a specific "group" involved in the project, as shown in Figure 4. Let's say Boeing is the contractor responsible for the Airframe, with Boeing Department 10 in charge of the wing and tail components. Users can take the Department 10 slice, and view all wing and tail deliverables, and associated wing and tail cost estimates and budgets. This is a great view for use by decision-makers representing any group, as they can get a customized view with only relevant information.

3. Input/Cost Model Structure Analysis

The previous sections have examined what features are required of the framework, and how the results should be reported. However, by analyzing the challenges faced by the cost estimator, we gained important insight into the best data structure for entering input drivers into the cost models. Cost model drivers generally fall into one of two categories that help frame this discussion: Product-Focused Drivers and Enterprise-Focused Drivers.

Product Focus	Enterprise Focus
▪ **Focused on the system being costed.** – Physical Architecture – Integration/Assembly – System Engineering/Project Management ▪ **Aids in Estimating** – RDT&E / Procurement Appropriations – Base Cost of Maintenance Actions (Cost of Spares/Repairs, Failure Rates) ▪ **Applications or Uses** – Proposals – Program Execution and Management – Design to Cost – CAIV for Engineering ▪ **Primary Users** – Cost Estimators – Contractors	▪ **Focused on the environment in which the system operates.** – Organizational and Operational Factors – Theaters – Force Structure ▪ **Aids in Estimating** – O&M, MILPERS, MILCON Appropriations – System operation within the context of force structure and operational concept. – Influence of organizational and theater factors on Maintenance costs. ▪ **Applications or Uses** – Budget Development – Program Evaluation – Affordability and AoA Analysis ▪ **Primary Users**

– Original Equipment Manufacturers – Program Managers	– Congress – G-8 Program Analysis & Evaluation – Cost Estimators

Table 3: Product-Focus vs. Enterprise-Focus Comparison

Product-focused drivers describe the physical architecture of the system, the points of assembly and integration of components, and the associated layers of system engineering and project management. Generally, these types of drivers are sufficient to estimate RDT&E and Procurement appropriations, as well as the base cost of maintenance actions, such as repair or replacement of a failed component. Our existing estimation framework (which was our starting point for this research project) was well-designed for this type of estimation. However, product-focused cost models can only estimate an incomplete portion of the total ownership cost. A method of describing the enterprise's context must be designed into the estimation framework.

Throughout our company's history, models and cost-estimating relationships have been developed for many activities in the O&M and MILPERS appropriations, though they often have been handled outside the estimation framework. As we redesigned this framework with TOC in mind, we had the luxury of using this wealth of existing information, which included major O&M/MILPERS cost drivers. We analyzed these drivers, with the goal of finding a structure to relate organizational and theater-specific drivers with product-focused drivers in a cohesive estimating framework.

The costs for O&M, MILPERS, and MILCON certainly depend on characteristics of the product, but also depend significantly on the environment(s) in which the product operates. These enterprise-focused drivers are intended to describe the relevant theater operational factors and organizational breakdown, which is informed by the hierarchy of force structure, fielding schedules, and infrastructure associated with the program, project, or system.

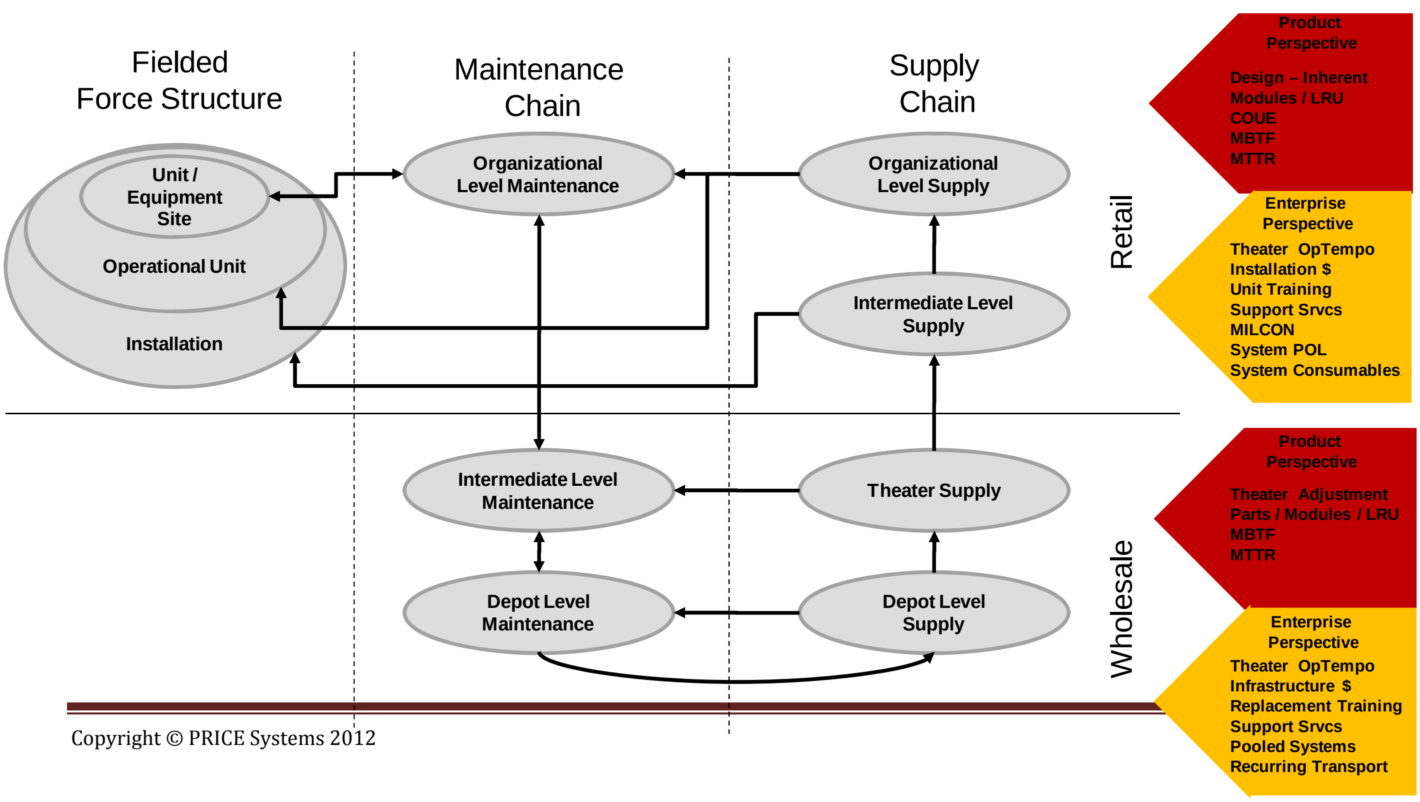

Figure 5: Force Structure and Organizational Relationships

As an example, how much does a system cost to maintain? Well, the frequency that system components will fail and need replacing depends on product characteristics such as mean-time between failures of product components; It also depends, however, on the environment in which it operates, including factors to account for harsher conditions (difficult terrain, extreme temperatures, high winds) and average operational tempo. In addition, the maintenance and supply chain costs depend on how many supply points and maintenance points are spread throughout the theater, how much stock these facilities keep, and how much it costs to ship spares from one facility to another. Figure 5 shows some of the force structure and organizational relationships that ultimately drive these costs. Other descriptors of this environment include MILPERS labor associated with support of the organization doing the maintenance (e.g. base operations), overhaul schedules, training schedules, turnover rates, permanent change of station rates, etc.

The TOC estimation framework design takes into account relevant product characteristics, organizational characteristics, and allows the user to define one or more theaters to further describe the environment in which the system will operate. All cost drivers were analyzed in terms of these categories, and the conceptual relationships between these data informed the underlying data structure of our cost models and how they interact with each other.

4. TOC Activity Completeness Analysis

This TOC estimation framework is intended for the aerospace and defense market, from the bottom of the supply chain up through the highest levels. This represents a wide and diverse set of systems that could be costed within the framework, and this begs the question “How can we be sure our framework accounts for everything that should be included in a TOC assessment?” In an effort to answer that question, we reached out to major aerospace and defense organizations such as the Army, Navy, NASA, UK MoD, CAPE (CAIG), NATO, etc.

These organizations each have their own standard cost breakdown structure (CBS), which are standard reporting formats, but can also be used as a checklist of cost elements that should be included in a TOC assessment. To ensure our framework and cost models represent a complete set of total ownership costs, we compared our models to the standard CBS’s of all those major A&D organizations. This also allowed us to take advantage of existing work in identifying the scope of a TOC estimate, while avoiding “reinventing the wheel.”

This comparison exercise involved reading detailed descriptions of every CBS element and comparing with every detailed description of the activities estimated in our cost models. We made notes of any costs missing from our models, any inconsistencies in definitions, etc. One by one, we addressed these issues with various experts, such as senior cost estimators, people experienced with DoD logistics, and internal cost model designers. In the end we addressed all issues, often researching and adding new activities to our existing models, or building completely new models. The end result was a TOC estimation framework that can handle an entirely comprehensive set of aerospace and defense programs.

Conclusion

Our goal was to design a conceptual framework to enable total ownership cost estimation and analysis for the broad set of stakeholders in the aerospace and defense community. By studying, in depth, the stakeholders of a TOC estimate, and breaking down the use cases of a TOC estimate, we developed a list of necessary framework features. Our research led to insights about the "cube" data structure, which enables reporting that satisfies all stakeholder requirements. We examined the product- and enterprise-oriented nature of the estimation model's cost drivers, which helped define an ideal, high-level, cost model input structure. Finally, a crosscheck with the standard cost breakdown structures of multiple major A&D organizations ensured that our model offerings are sufficient to provide a complete total ownership cost assessment.

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