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The Shortcomings of Cost Estimating Templates

Meagan Gadreault, Faye Kim

Contents

Table of Figures

Introduction

Standardization implements technical standards to maximize interoperability, repeatability, and increase quality in many processes. Standardization is typically seen in manufacturing industries where it is essential to reduce waste and minimize errors. However, the consistency that standardization provides has become a common goal for other industries to achieve highly efficient businesses. This is no different in the Department of Defense (DoD). The DoD is one of the largest government entities, so standardization is critical for successful operations nationwide. Standardization objectives in the DoD are achieved through use of Military Standards.

The DoD is responsible for a $580.3B budget for FY2016, and the Navy's budget is $168.8B per the FY2016 Budget[1]. The DoD budget guides the direction of the United States Defense programs, and these programs are crucial for maintaining high national security standards. Each year, different organizations and programs are responsible to accurately predict the costs of their program and submit their proposed budget. Cost estimators are fundamental in securing the appropriate amount of funding to support a program's success. Cost estimators produce guidelines for accurate budget submissions, which enable a project to be completed with the highest standards. This ensures that budgets are not too high and that organizations within the DoD are reducing superfluous spending and maximizing their budget. Since multiple cost estimates are created throughout a program's life cycle, their standardization is important as the results provided in each estimate can directly impact the direction of the DoD. If standardized practices were used to create estimates, we would ensure continuity between each effort and that estimates can accommodate changes in program requirements.

[1] https://www.defense.gov/News/News-Releases/News-Release-View/Article/652687/department-of-defense-dod-releases-fiscal-year-2017-presidents-budget-proposal

Purpose

Developing an estimate takes a long time and often uses estimates from previous milestones within the same program of record as a baseline. Estimates are created inefficiently because they can be tedious, lack traceability, and require long lead times. They also are missing a complete dynamic capability to handle changes to the program requirements. To ensure that these changes do not cause errors, estimates need to be manually checked for calculation errors and accurately roll-up to the summary page of the model.

The purpose of this paper is to utilize lean six sigma techniques to identify the causes of inefficient cost estimate modeling, propose a method to improve efficiency, and discuss future efforts incorporating the recommendations outlined in this paper.

Background

Cost estimating

Figure 1: A schematic of the cost estimating process

The overall high-level process for cost estimating is shown in Figure 1 (the order of the steps is directed by the arrows, and the double arrows in the figure indicate that steps can occur concurrently). The entire process starts off with the project kickoff. In this step, the requirements for the project are outlined and a notional timeline is established. The next steps of the cost estimating process are the data collection, the data analysis, and modeling. These steps should occur sequentially but often occur concurrently, as seen by the double arrows in the Figure 1. The data collection step is based on the requirements established at the kickoff meeting and are dependent on a program. The data collection is the longest portion in completing a cost estimate as stakeholders do not always have the desired information needed to create a credible cost estimate. This leads to a lot of data requests to stakeholders which are rarely provided back to estimators completed or accurately. In the data analysis step, cost estimators take the data inputs and determine which values are the best and most appropriate to be used in the build-up of program costs. The modeling step is when the cost estimator takes all the data inputs and uses the raw data to calculate summary costs. In this paper, the modeling is specific to MS Excel. Working with incomplete data in the data analysis and modeling phases results in rework as the data becomes available. The overall product is delivered when the model has been completed by cost estimators.

Lean Six Sigma

Six Sigma is a set of techniques that is used for process improvement by identifying and removing the causes of defects and minimizing variability in an effort for standardization. It was introduced in the 1980s by a Motorola engineer and its success led to its early adoption and integration in General Electric's business strategy[2]. Since then, companies have widely implemented Six Sigma to improve quality and increase profits. Lean Manufacturing focuses on eliminating waste within a manufacturing system. Toyota's successful growth from a small company to a large automaker can be attributed to instituting Lean Manufacturing by focusing on factors that improve overall customer value[3]. Lean Six Sigma is a process that combines Lean Manufacturing and Six Sigma to improve the quality of a product by minimizing variability, removing causes of defects, and reducing waste. The origins of Lean Six Sigma can be traced to 2001, and since then, more businesses have transitioned to using Lean Six Sigma.

[2] http://asq.org/learn-about-quality/six-sigma/overview/overview.html
[3] https://www.lean.org/WhatsLean/

Lean Six Sigma has typically been implemented in the manufacturing industries but has become more prevalent in other industries due to its proven success in quality improvement. For example, Lean Six Sigma has been used in healthcare[4], a field that is not typically associated with manufacturing, to "improve patient safety by eliminating life-threatening errors." Similarly, we can leverage Six Sigma techniques to cost estimating to start to reform the cost estimating process.

One of the main Lean Six Sigma techniques that is used to improve processes is the DMAIC strategy[5]. DMAIC is an acronym for the five phases that make up the quality improvement process:

- **D**efine the problem
- **M**easure performance through metrics
- **A**nalyze the process to determine root causes of variation and/or defects
- **I**mprove the performance by implementing solution that addresses root causes
- **C**ontrol the improvement for future process performance

We will be using the DMAIC process to find the root cause of inefficient cost estimating and propose a solution to improving cost estimates.

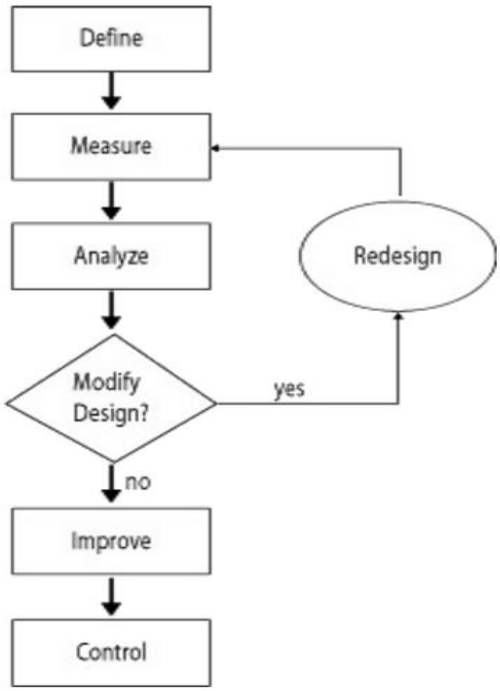


Figure 2: A process map detailing the DMAIC process. Reproduced from GoLeanSixSigma.com[6]

Scope and Limitations

The scope of this paper is the modeling step of the cost estimating process as this is the step where cost estimators can have the greatest impact. The availability of the data is uncontrollable by cost estimators, so the data collection step of the cost estimating process is outside the scope of this paper. Also, the data analysis step of the cost estimating process is outside the scope of this paper.

The biggest challenge for this paper was gathering supporting data. An estimate's duration should be easily measurable and comparable to other programs as each estimate effort has definitive start and end dates. However, numerous factors for variation in programs contribute to the difficulty in collecting numerical data. The measurable data discussed in this paper is scalable qualitative data, and the specifics of the data are discussed in a later section.

[4] http://asq.org/healthcaresixsigma/lean-six-sigma.html
[5] http://asq.org/learn-about-quality/six-sigma/overview/dmaic.html
[6] http://asq.org/learn-about-quality/six-sigma/overview/dmaic.html

Another challenge to this paper was the substantial amount of time that was required to collect data and metrics for DMAIC. Ideally, the metrics should be collected before and after process improvement efforts to determine whether process improvements occurred. However, as the development of cost estimates can take upwards of six months, mass measurement of collecting qualitative data would have required significant amount of time and was outside of the scope for developing this paper. Thus, the Measure and Analyze phases of the DMAIC process, outlined in the follow section, discuss a proposed method to measure qualitative data for improving the cost estimating process.

Cost Estimating Process Improvement

DMAIC (Define, Measure, Analyze, Improve, Control) is Lean Six Sigma's foundational process that aims to improve performance by identifying root causes of defects and variation and measuring improvement through metrics[7]. This section of the paper will outline how DMAIC can be used to improve the cost estimating process.

Define

Estimates are arduous and not easily transferable between analysts making the cost estimating process inefficient. Estimates contain poorly defined assumptions, have no supporting documentation, are characterized by poor data collection, and can be supported by irrelevant or inadequate data. Estimates are updated throughout a program's lifetime and personnel changes often occur, which can lead to a loss of institutional knowledge with every transition. Additionally, if estimates are created using poor Excel techniques and have hard-coded values in the build-up, it is difficult to run future drills and a lot of rework is required to account for the changes in the program. This inevitably causes long lead times as analysts need to familiarize themselves with the estimates and troubleshoot problems caused by poor Excel modeling techniques. These difficulties in understanding the model have been expressed by the end user's input.

Six Sigma surmises that variation causes error. However, there is a high degree of variation in the cost estimating process, and minimizing variation can decrease the long lead time of estimates. Factors that influence variation include: the number of requirements, the length of the programs, the complexity of the estimate, and number of items that need to be estimated. These factors are mostly externally-controlled, and analysts have few opportunities to mitigate these issues. The uncontrollable variation in the cost estimating process is the main reason why empirical numerical data is an unreliable metric for process improvement. Comparing process durations is a fruitless effort because the programs' requirements, complexity, and type of estimate are not analogous for an apples-to-apples comparison. Due to the high variation, metrics provided through direct feedback from cost estimators are more critical measurements in our process than numerical duration metrics.

Measure

Data could not be collected and utilized for this paper as the time required to gather this information was too extensive. This section is structured around questions dictating the proposed process on the data collection.

[7] http://asq.org/learn-about-quality/six-sigma/overview/dmaic.html

What kind of data will be captured?

As discussed in the previous section, feedback from cost estimators provides the most reliable source of data. Cost estimators have indicated their frustrations when inheriting a previously developed model. A great amount of rework is required to properly maintain or update models, and it is especially difficult if models lack traceability. Relevant metrics need to be captured to create a baseline for process performance.

To improve the quality of the cost estimating process, qualitative variables to track user feedback are necessary. The following qualitative metrics that should be captured include, but are not limited to:

- Ease of use of model
- Traceability
- Dynamic measures / Ability to handle changes of scope

These metrics can be captured on a numerical scale (low to high) where the magnitude is clearly defined.

From who will this data be captured?

The population for this data collection include cost estimators. For this example, assume there are 10 cost estimators who each work on an average of two estimates. These estimators are the population from which we would collect sample data to create a sample size of 20 data points. It is important to explicitly define the users from which data will be collected, and the best data can be collected from cost estimators themselves. Additionally, data from end users can be collected to supplement the information captured.

How will the data be captured?

The data will be captured by using surveys at the initiation of the project, and the metrics will assess estimators' overall satisfaction with the current cost estimating process and the state of an existing estimate.

How can we ensure that the data is reliable?

Since the data is anecdotal, we cannot apply the same reliability checks that we would be able to for empirical numerical data. However, there are different options available to us to ensure that we are collecting reliable data.

One method to ensure data reliability is to gather data points from as many cost estimators as possible. With an increased sample size, we can be more certain that the drawn conclusions are more widely applicable. The data collection survey should also include a comment box after each question where the participant can provide reasons for why a rating was given. This would enable us to tie keywords or phrases to a rating in order to be more specific in our improvements.

What would the data show us?

Based on conversations with multiple estimators, we assume that the data would back up the claim that most people involved with the cost estimating process agree that the process is inefficient. We suspect that:

- Users will rate the ease of use for a model low
- Users will rate traceability low.
- Users will rate the dynamic measures to be absent/minimal

In this hypothetical data collection, we assume the survey results to be negative based on personal experience and limited candid feedback. These assumed results were the driving force behind the process change for the modeling portion of cost estimating. .

Analyze

The root cause of problems in the cost estimating process needs to be determined in the analyze portion of the DMAIC process. One of the Lean Six Sigma techniques that we utilized is the fishbone diagram.

Per the American Society for Quality (ASQ), a fishbone diagram is useful to identify "many possible causes for an effect or a problem" [8] in a brainstorming session. There are three elements to a fishbone diagram. The *head of the fish* is setup with the problem statement. Broad categories group the root causes together and make up the *fishbones*. Individual causes within each category that may affect the problem are then identified. Additional sub-factors can further be identified. Figure 3 reveals the numerous possible causes that can lead to inefficient development of cost estimates.

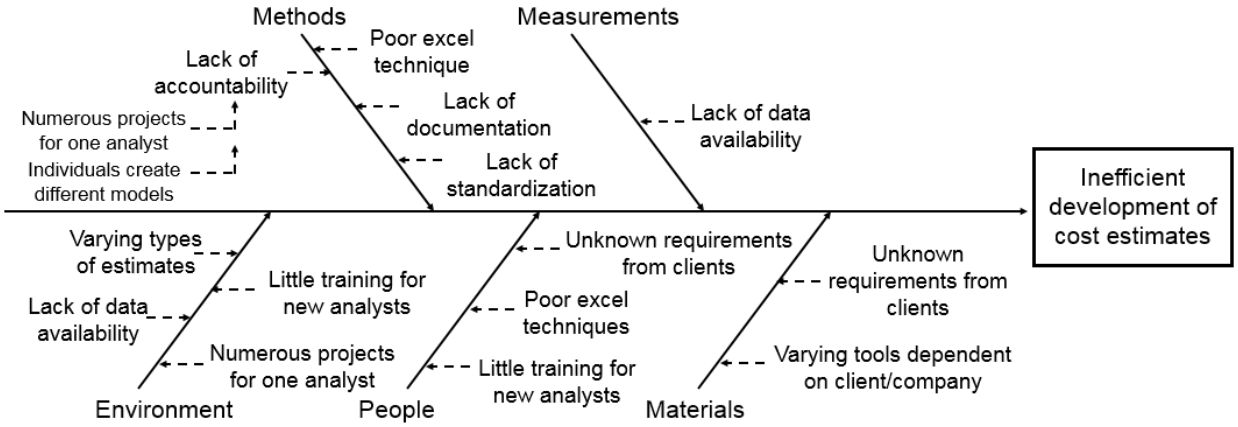


Figure 3: A fishbone diagram that was created to determine root causes of developing cost estimates

[8] http://asq.org/learn-about-quality/cause-analysis-tools/overview/fishbone.html

The broad categories that were used to group the root causes together were measurements, methods, environment, people, and materials. They can be described as:

- Methods: how process is performed and necessary requirements
- Measurements: data from the process
- Environment: conditions in which process operates
- People: anyone involved with the process
- Materials: raw materials that are used to produce final product

Ten unique causes were identified across these broad categories to contribute to inefficient cost estimate development. An analyst often must work on numerous projects in tandem and that increases the time spent to be reacquainted with a model. Poor excel technique would inhibit an estimator to understand a model fully to improve it. Lack of documentation (data sources, rationale with the calculations) within the model make it difficult for estimators to create consistent estimates for each estimation effort. Lack of standardization in general creates variability. The varying types of estimates create different requirements that need to be captured for the estimates. The lack of data availability requires data collection, data analysis, and modeling to occur concurrently which increases lead times of estimates. If new analysts are not well trained, analysts cannot improve or create models. Estimators cannot properly proceed to develop the model if the client does not completely know what is desired. Additionally, some agencies will use a specific program other than Excel (e.g., ACEIT) and time is required to learn the program.

Upon completion and observation of the fishbone diagram, it became apparent that templates already aim to address most these causes. Therefore, we grouped the different causes into the three broad categories based on template implementation as a solution. The categories are:

- Causes that we are unable to control and will not address in this paper;
- Causes that are critical in developing reliable estimates but are not solved with templates;
- Causes that directly lead estimators towards creating templates for cost estimating model.

To be thorough in our evaluations, we will go through each cause and its possible implications.

Improve

The improve phase focuses on identifying current waste, defining potential solutions and future state, and is divided into 4 sections. The first section focuses on the results of the fishbone diagram and the specific grouping that was utilized. The following section looks specifically at the final grouping (causes that directly lead estimators towards creating templates for cost estimating model) to provide a more in depth analysis of current template implementation. The analysis covers how templates are currently being implemented to address a root cause, and is then countered with ways that templates fail to completely address the cause of inefficiency.

Next is our proposed list of best practices as a solution to the lack successfully implemented templates. Finally, we discuss a way forward and plan on how we are going to measure the success of our proposed solution.

Results

Uncontrollable Causes

There are three causes we have identified as uncontrollable but are important to consider when measuring the efficiency of developing a cost estimate. These causes are:

- Unknown requirements from clients;
- Lack of data availability;
- Lack of accountability - numerous projects for one estimator;
- Varying tools dependent on client/company.

In an ideal state, we would have all information and every detail about the program being estimated, but that is rarely the case. There are always going to be circumstances where there will be unknowns with the data requirements, and because these are provided by program stakeholders, it is harder control the process. There is also an issue with the availability of data. As estimators, we want to collect as much data as possible, but often the client does not have the data we want or in a format that is useful. While this process can improve greatly, it is not directly controlled by an estimator, and therefore we will not consider that as a viable process to fix in this paper. Additionally, cost estimators cannot control the tasking assigned (and thus cannot control the number of estimates that need to be developed) nor the tool that program stakeholders want to utilize to build up a cost estimate. No process change can occur to alleviate these causes.

Controllable Causes Outside of Scope

After identifying all the causes that cannot be controllable, there were two identified causes that could be improved to make this process more efficient:

- Lack of training for new analysts;
- Lack of modeling documentation for future use.

The lack of modeling documentation is important to facilitate the transparency between model iterations. However, this is not a direct output of the physical model and is not currently being addressed by template implementation. Current template implementation does not address the lack of training for new analysts and does not supply supplemental resources for new analysts. Although these causes are not currently addressed by template implementation, they may be alleviated with a different problem solution.

Causes That Result in Templates for Cost Estimating Models

Templates are a technique used to standardize process and improve efficiency. In the cost estimating world, numerous cost estimating templates have been created to improve the cost

estimating process. Templates work to alleviate the numerous causes of an inefficient process. The causes include:

- Lack of standardization;
- Poor excel techniques;
- Lack of documentation;
- Lack of accountability - individuals create different models

Despite what seems like a clear solution, it is rare to see an estimator defer to using a cost estimating template.

Templates as a Solution to Process Improvement

Current Excel-based cost templates strive to create standardization for cost modeling. In theory, templates create a method to provide a cost estimate that is easily transferable, traceable, and repeatable. Cost estimating templates are usually built from generic Work Breakdown Structure (WBS) and are used to create total costs for varying elements within the WBS. The DoD uses the standard practice document MIL-STD-881C to standardize the organization of cost elements for defense material items. To streamline the flow of data, the WBS in current templates is broken into smaller sections and pre-linked at the lower information levels to roll up to a summary page. Pre-linking cost placeholders for each WBS element to a high level aims to reduce the time it takes to recall information in cells in later steps of the modeling. All cost estimating templates have an inputs page for data and a section to identify the source of data.

While standardization efforts are necessary to make the estimates easily transferable, maintainable, and understandable, standardization is not correctly addressed to solve the current root problems.

Current Implementation and Shortcomings

Poor excel techniques, lack of documentation, individuals create different models resulting in a lack of accountability, and lack of standardization were four identified causes that templates strived to solve.

Poor excel techniques consist of hard coding values within model, lacking database structure to organize data and the WBS, and missing source documentation and rationale for data inputs. Templates try to address this cause by incorporating an inputs page for the user to have all data entries centralized on one page with any associated risk values, and a place to document the source/rationale for every input. However, current templates do not fully address the cause it is trying to solve. In current templates, the inputs page is perfectly structured to readily accept data to be inputted with the information comprehensively outlined. One shortcoming of the inputs page is that it is underutilized when there is a pressing deadline or if the user does not see the importance of a centralized data location. Additionally, templates currently do not address the need for database structure to set up a WBS.

While the goal of templates is to reduce variability, no amount of standardization can fully account for inherent variation caused by the individuals building up a cost estimate. Estimators have different ideas on how to create estimates and each estimate we create will inherently be unique. Even if two users were presented the same data to use in the same template, it is likely that users would arrive at the same product as individual artistic liberties were taken to create the estimates. This defeats the purpose of standardization through templates.

Templates generally create a standardized method to input project requirements and seamlessly create a framework that is identical across every cost model. This allows cost elements to be easily found in a model. Despite its apparent benefit, templates are quite rigid as they are built off idealized Work Breakdown Structures (WBS) and do not take into consideration any variability in a program. As each program's requirements are quite different, it is difficult to map these unique inputs to a standardized model. Attempting to do this reduces the flexibility that cost estimators require to deliver high-quality products.

Additional Concerns from Templates

Pre-defined WBS that links into lower levels can cause breaks in the model even before any data is entered. If rows or columns are to the general WBS summary page, then users risk decreasing traceability and increase the amount of error checking at all lower levels to ensure changes are correctly captured. In addition, the suppression of creativity occurs when templates are used, and this is detrimental to creating innovative cost estimating templates as templates force analysts to create models in a constrained framework.

Best Practices as a Solution for Process Improvement

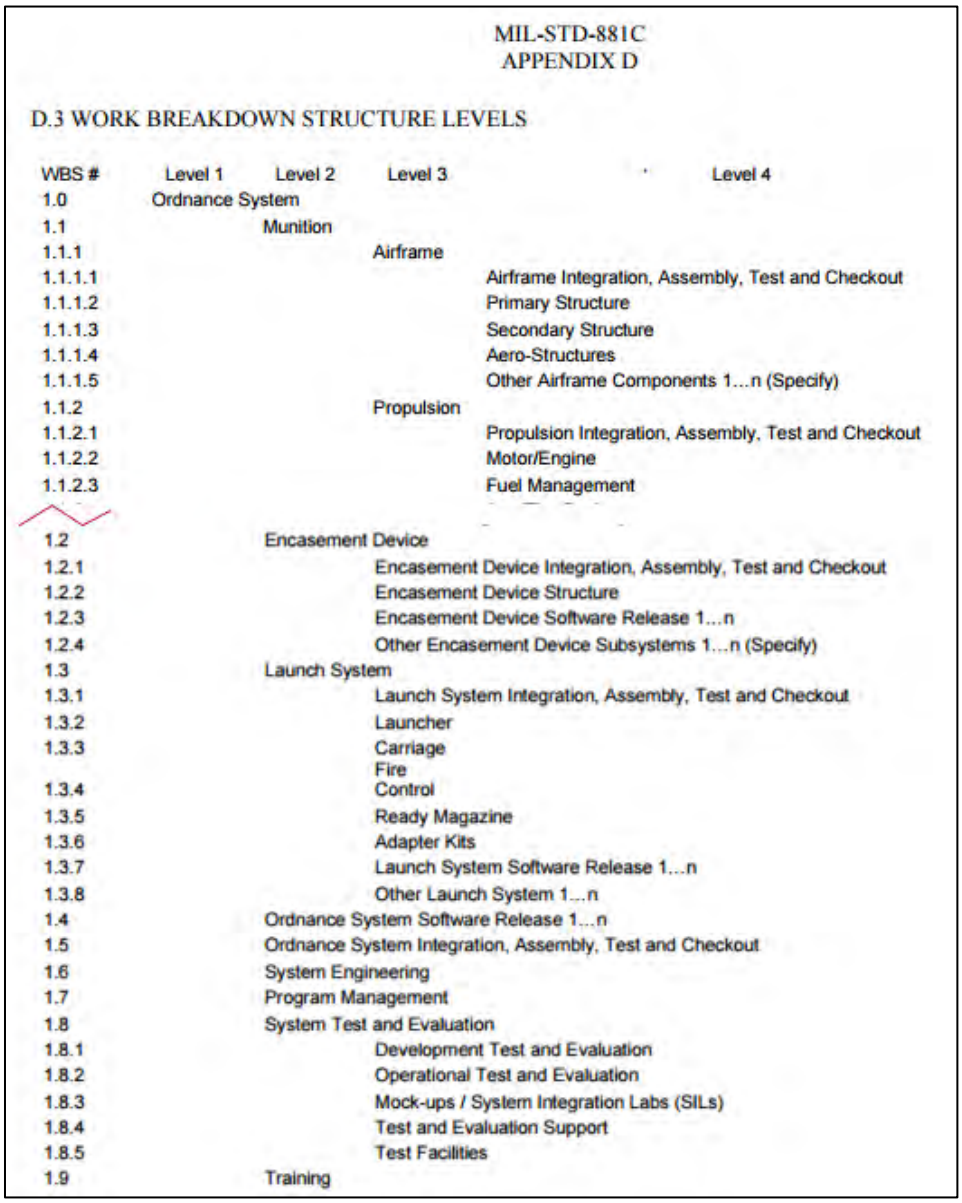
It can be concluded that current cost estimating templates are not effective. There is likely a template that can be created that addresses all the concerns that were expressed in this paper. However, the idealized template would only solve problems where the WBS are available in its entirety and is not a solution to all cost estimates. Therefore, a solution needs to be created that can be used for every situation.

The proposed solution that can be used in every scenario to improve the cost estimating process is creating a set of best practices and implementing them. The suggested best practices are a list of requirements that have been gathered through our experiences as new cost estimators and guidance for successful estimates from more experienced cost estimators. These best practices consist of methods that are measurable, notably successful, and replicable.

The best practices are as follows:

1. Use MIL-STD 881C to finalize the first two levels of WBS elements. The third level of elements is program-specific.

Depending on the system, MIL-STD 881C contains WBS structures that can be used as a framework from which cost estimates can be built. These systems include: aircraft, electronic, missiles, ordnance, sea, space, surface, unmanned air vehicles, unmanned maritime vehicles, launch vehicles, automatic information systems, and common elements. If a program cannot be categorized into any of the systems listed previously, the common elements WBS should be used. A screen capture of a WBS can be seen in Figure 4.



MIL-STD-881C
APPENDIX D

D.3 WORK BREAKDOWN STRUCTURE LEVELS

WBS #	Level 1	Level 2	Level 3	Level 4
1.0	Ordnance System			
1.1		Munition		
1.1.1			Airframe	
1.1.1.1				Airframe Integration, Assembly, Test and Checkout
1.1.1.2				Primary Structure
1.1.1.3				Secondary Structure
1.1.1.4				Aero-Structures
1.1.1.5				Other Airframe Components 1...n (Specify)
1.1.2			Propulsion	
1.1.2.1				Propulsion Integration, Assembly, Test and Checkout
1.1.2.2				Motor/Engine
1.1.2.3				Fuel Management
1.2		Encasement Device		
1.2.1			Encasement Device Integration, Assembly, Test and Checkout	
1.2.2			Encasement Device Structure	
1.2.3			Encasement Device Software Release 1...n	
1.2.4			Other Encasement Device Subsystems 1...n (Specify)	
1.3		Launch System		
1.3.1			Launch System Integration, Assembly, Test and Checkout	
1.3.2			Launcher	
1.3.3			Carriage	
1.3.4			Fire Control	
1.3.5			Ready Magazine	
1.3.6			Adapter Kits	
1.3.7			Launch System Software Release 1...n	
1.3.8			Other Launch System 1...n	
1.4		Ordnance System Software Release 1...n		
1.5		Ordnance System Integration, Assembly, Test and Checkout		
1.6		System Engineering		
1.7		Program Management		
1.8		System Test and Evaluation		
1.8.1			Development Test and Evaluation	
1.8.2			Operational Test and Evaluation	
1.8.3			Mock-ups / System Integration Labs (SILs)	
1.8.4			Test and Evaluation Support	
1.8.5			Test Facilities	
1.9		Training		

Figure 4: An example work breakdown structure that was altered and reproduced from MIL-STD 881

One of the most important things to be gleaned from using MIL-STD 881C is to use every element that is outlined in the standard even if the original scope does not require a specific WBS element. By including every element of the WBS structure as outlined by Levels 1 and 2,

you can minimize the number of additional elements that could potentially be added due to scope changes.

2. Utilize database structure to organize cost elements in WBS

Database structure requires data to be broken down to the lowest sub-level based on the WBS This structure avoids the use of merged cells to categorize data and often results in duplicative entries in the row. While it may seem counterintuitive to repeat information, this enables a cost estimator to utilize pivot tables which are essential in cost modeling. This improves the model quality and accuracy and reduces human error.

#	CES Level 0	CES Level 1	CES Level 2	CES Level 3	CES Level 4	CES Level 5	Funding Source	APPN
1	1.0 Research & Development	1.1 Munition	1.1.1 Guidance and Control (G&C) Section				Internal	RDTEN Composite
2	1.0 Research & Development	1.1 Munition	1.1.2 Warhead Section				External	RDTEN Composite
3	1.0 Research & Development	1.1 Munition	1.1.3 Fuel Tank Section					RDTEN Composite
4	1.0 Research & Development	1.1 Munition	1.1.4 Afterbody/Tailcone Section					RDTEN Composite
5	1.0 Research & Development	1.1 Munition	1.1.5 On Board Test Equipment					RDTEN Composite
6	1.0 Research & Development	1.1 Munition	1.1.6 On Board Training Equipment					RDTEN Composite
7	1.0 Research & Development	1.1 Munition	1.1.7 Auxiliary Equipment					RDTEN Composite
8	1.0 Research & Development	1.1 Munition	1.1.8 Munition Software Release 1...n					RDTEN Composite
9	1.0 Research & Development	1.1 Munition	1.1.9 Munition Integration, Assembly, Test and Checkout					RDTEN Composite
10	1.0 Research & Development	1.2 Encasement Devices						RDTEN Composite
11	1.0 Research & Development	1.3 Launch System						RDTEN Composite
12	1.0 Research & Development	1.4 Ordnance System Software Release 1...n						RDTEN Composite
13	1.0 Research & Development	1.5 Ordnance System Integration, Assembly, Test and Checkout						RDTEN Composite
14	1.0 Research & Development	1.6 System Engineering						RDTEN Composite
15	1.0 Research & Development	1.7 Program Management						RDTEN Composite
16	1.0 Research & Development	1.8 System Test and Evaluation						RDTEN Composite
17	1.0 Research & Development	1.9 Training						RDTEN Composite

Figure 5: An example of a model that uses database structure[9].

The database seen in Figure 5 has a similar framework to the example WBS structure that is seen in Figure 4. The first two levels (level 0 and level 1) are identical to MIL-STD 881-C, but CES level 2 provides program specific cost elements.

[9] Cost Estimate developed by Herren Associates, Inc.

3. Need all cost inputs in the same units and cost elements labeled with appropriations
When performing any type of cost estimate, cost values must be normalized to account for inflation. All cost inputs need to be converted to common year (CY) values or base year (BY) values to directly compare costs. For example, if cost estimating occurs in FY16, historical data inputs from FY02 need to be converted to CY16 dollars. The separation of data inputs by fiscal year can be seen by Figure 6.

				FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25
CES Level 3	APPN	QTY	CY15$ PE	CY15$ PE FY18	CY15$ PE FY19	CY15$ PE FY20	CY15$ PE FY21	CY15$ PE FY22	CY15$ PE FY23	CY15$ PE FY24	CY15$ PE FY25
	RDTEN Composite			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	O&MN Composite			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	OPN			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	WPN			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Figure 6: A sample model that shows cost inputs categorized by fiscal year and appropriation[10].

Furthermore, it is likely that a program will experience schedule slips and changes to the procurement profile, so estimators should preemptively include the framework for at least ten additional fiscal years following program end of life to account for any additional years that may incur costs.

4. Place all data into a single inputs page and link the rest of the model to this page.

Creating an inputs page is not a novel concept. Using an inputs page has been widely implemented in the cost estimating industry to reduce errors that can occur with hardcoded values. Despite the best intentions of an inputs page, data can end up being hard-coded into a model for estimates that have tight deadlines. This is a simple fix to create an accurate cost estimate in a timely fashion but will inevitably cause difficulties in sustaining the cost model. It is critical to only update values on the input page regardless of any time constraints so they are traceable in later model usage.

5. Cite the source of all assumptions and provide comments/documentation.

This allows for transparency and sustainability of the model so that it can be easily transferred to other users. All sources and rationale for each cost input should be included on the inputs page to maintain the centralized location of all raw data.

6. Use multiple cells to break down formulas into easy parts.

[10] Cost Estimate produced by Herren Associates, Inc.

If complex (or over-engineered) formulas are not broken up, models are difficult to understand and update in future estimating efforts. This reduces the traceability and sustainability of a model.

7. Build everything that is needed in the model in the single Excel spreadsheet.

Do not link to any external files. This will ensure that the model will not break due to missing files due to incorrect file paths. If information is needed from a separate file, the data need to be incorporated in the model through the raw inputs page and careful attention is needed to source the documentation.

8. Use standardized template for certain aspects to cut time.

In some instances, there are aspects of cost estimating that can utilize templates. These aspects include inflation and risk. These are unchanging with respect to each template and can reduce the amount of time spent on cost estimates.

These best practices can be utilized be cost estimators at any experience. Seasoned cost estimators can use the guidelines as quick reference, and new cost analysts can utilize the guidelines as a learning tool to instill the best practices before even beginning their own cost estimate

Way Forward

Measuring Success

After implementing the list of best practices when building a cost model, it is important to go back and measure whether the cost estimating process changed. We want to collect data to determine if actual improvement occurred. The metrics obtained at the product delivery will assess the population's satisfaction after the proposed solution is implemented. Using the same techniques as described in the Measure phase, we would collect the same metrics to ensure we can have an apples-to-apples comparison of feedback related to ease of model, traceability, and dynamic capabilities. Once appropriate data is collected, we can perform a data analysis to determine the change in qualitative metrics and evaluate if the process was improved.

Potential implications of the solution

Although the best practices sound reasonable and implementable on paper, there are a few implications to acknowledge. Currently, the cost estimating community has yet to adopt these best practices. The main deterrent is the lack of captured data. Support from the industry is needed to gather enough information to prove that these best practices can improve the cost estimating process.

We briefly discussed that a cause of inefficient cost estimates is the lack of training for new analysts. If we can provide a guide/example of best practices for them to implement it can serve

as a beneficial training tool to produce better/more efficient cost estimators. If we can instill best practices in new analysts before the develop their own style then the changes could be successful, but there is no measurement that can prove

Control

To facilitate continuing improvement, a control procedure needs to be developed to ensure proper transfer of knowledge. This control plan provides a summary of the process knowledge that was obtained through the process improvement process. In other words, the control plan is the list of best practices.

The most important aspect to maintain an efficient process is to constantly review and update the proposed guidelines as necessary.

Eventually, after ensuring that improvement occurred through implementation of best practices, further metrics need to be identified to maintain performance improvement to a greater degree.

Conclusion

The purpose of this paper was to show that process improvement methods that are prevalent in other industries can be applied to the cost estimating industry. Lean Six Sigma techniques were used to find the root causes of inefficient cost estimates, and solutions to these causes were explored. Templates are one solution that is in practice. We are still able to identify areas of improvement in current template implementation. A proposed method in quantifying improvement was discussed. Process improvement is most likely to be achieved by using a set of best practices as a learning tool for inexperienced cost estimators and as a quick reference for more experienced estimators.