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Supplement to the Project Cost Estimating Procedure (12.PM-005)

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CHANGE LOG

This version of the document may not be the most current approved revision. The current revision is maintained on the OPSS SharePoint site.

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V0	4/11/2016	First thoughts
1.0	3/17/2017	Initial version

Contents

1 INTRODUCTION

The purpose of this supplemental guide to EVMS Cost Estimating Procedure 12.PM-005 is to provide information that assists projects in producing the best point cost estimates possible. It does not replace the cost estimating procedure 12.PM-005, which is the authoritative document on what is required. It instead discusses the importance of accurate cost estimating, and provides information intended to help the “boots on the ground” cost estimator. The total project cost will ultimately include a base cost, cost uncertainties, and risk contingencies. This guide does not cover development of uncertainty or risk estimates.

A cost estimate is the summation of individual cost elements using understood, documented methods and data to estimate the total cost of a DOE 413.3 Project. It can also refer to the process of forecasting or approximating the time and cost of completing separate project deliverables. The management of a cost estimate involves continually updating the estimate with actual data as it becomes available, revising the estimate to reflect changes, and analyzing differences between estimated and actual costs using data from the earned value management (EVM) system. The ability to generate reliable cost estimates is a critical function, necessary to support Fermilab’s mission. Without this ability, projects are at risk of experiencing cost overruns, missed deadlines, performance shortfalls, and potentially cancellation.

An integrated, process-centered, and disciplined approach to managing the cost of projects provides real and tangible benefits to all project stakeholders. This in many ways begins and ends by developing and maintaining realistic estimates of what those projects will cost. Through upfront planning and cost-risk performance analysis, risks inherent to the successful delivery of the project on time and within budget are minimized. Additional desireable results include, but are not limited to the following:

- Early recognition of interface requirements and constraints
- Complete, unambiguous, and documented functional requirements and acceptance criteria
- More accurate, credible, and defensible scope, cost, and schedule estimates
- Timely and more effective risk mitigation
- Earlier and more consistent visibility to problems (fewer surprises)
- More efficient project management through structured systems that allow easy access to the most pressing issues
- Historical data to gauge process improvements and effectiveness
- Promotion of organizational credibility and reputation

Understanding the type of estimate that is required is important for the people making the cost estimate so they provide useful, accurate data to the decision makers. Cost estimates are key elements of a project plan and project personnel expend considerable effort preparing them. They provide the basis for programming the total requirement and the recommended phasing of budgets. Obtaining accurate cost estimates can be difficult as Fermilab projects usually involve new technologies and require years to complete. Inaccurate estimates can result from an inability to predict and/or define requirements, technological advancements, task complexity, economic conditions, schedule requirements, support environments, or system employment concepts adequately.

Managers sometimes feel pressured to provide optimistic estimates in order to obtain project approval from the lab and DOE. However, a poor cost estimate of any type ultimately has negative consequences for everyone. A poor cost estimate causes loss of institutional and stakeholder confidence in our ability to do projects well, and can have impacts far beyond the project itself. Accurate and reliable cost estimating has a direct, positive impact on Fermilab.

Overestimating the Total Project Cost (TPC) may result in the program appearing to be unaffordable, or may mean that other opportunities to do science are lost because more funds than needed are tied up. Underestimating the TPC will prevent decision-makers from allocating the proper funding required to support the project. Properly estimating cost supports the budgeting and funding profile process. Repeatable and documented estimates allow “apples to apples” comparisons to occur, supporting the decision-making process of the lab, the DOE, and the field about what science is pursued and funded.

2 SCOPE

This document provides the Project staff with non mandatory supplemental information to the FRA Cost Estimating Procedure 12.PM-005 consistent with and complementing the Fermilab Engineering Manual. The Department of Energy Cost Estimating Guide, DOE G 413.3-21 updated 22-Oct-2015 provides high level, non mandatory approaches.

3 THE COST ESTIMATING PROCESS

There are three main parts to the 12 step cost estimating process described in the Fermilab procedures, which follow the GAO and DOE guides:

1. Project Definition
2. Determining the Cost Methodology
3. Making the Cost Estimate

The first part of the cost estimating process is called the Project Definition, which is well defined and motivated in the procedure and in the GAO and DOE guides, so we just summarize the key points in this document. During this part the project defines expectations and begins to understand and capture the project scope, which is crucial. In early phases of a project there will be many unknowns. As the estimate is being developed and data are gathered, a Work Breakdown Structure and technical description are formed. These items help define the project and form the foundation for the estimate. As the estimators continue through the estimating process, these steps may be revisited as new information is obtained. The Work Breakdown Structure contains all the elements of the project, and its organization defines the subsequent subsystem cost element scopes. A critical takeaway, and worth repeating, is that the WBS contains all elements of the project. The most common way to get the cost estimate wrong in any project is to leave out elements.

The second part of the cost estimating process, Determining the Cost Methodology, includes tasks that create the approach and framework for the estimate, and this document expands on the procedure and guides with some useful tips in subsection 3.1 below . Developing the ground rules and assumptions will be the most revisited task in this part of the process. As methodologies are selected and the data are gathered, the ground rules and assumptions, methodologies, and even the cost model may be refined, as appropriate.

The third part of the cost estimating process, Making the Cost Estimate, has tasks that include the actual conduct, presentation, and maintenance of the cost estimate. All of these tasks are important in their own right, and together, they become critical for a defensible and complete estimate. Extracting real, concrete steps or processes to get as close as possible to correct cost estimates is one of the things that is most difficult to get at in the process or guides, so subsection 3.2 below includes real world examples and hands on things that cost estimators can do.

As noted above, the cost estimating process is usually shown as a series of successive steps. It is in practice often an iterative process. For example, the initial estimating results may be revised one or more times because of changes to the technical and programmatic baselines, questions about the sensitivity of results, changes in ground rules and assumptions, or indications that the estimate is not complete. The revised results and findings are then documented and, along with the estimating models and data, made available for subsequent estimating and analyses. The focus of this guide is to identify and communicate practical, actionable ways that projects can take in each of the three steps.

3.1 Cost Methodology

There is a large body of work on estimating costs for all kinds of things. They have many different names, and different times when they are applicable. In the procedure for cost estimating 12.PM-005, the cost estimate class is defined from level 1 to 5. There, the level classification is determined by how well the thing being costed is defined, with level 1 being very defined, and level 5 being hardly defined at all. The list of classifications references various methods used to develop the different class levels. Some of the common methods are:

3.1.1 Analogous Estimating

Top down, or analogous estimating, is done to get an overall project estimate when there are not really many details available. Usually it is arrived at by comparing the proposed project to a similar one that was done in the past, for which the final answer is known. For civil construction or other projects with known conditions, this can give reasonable results, but in general for Fermilab projects the estimate uncertainty associated with this technique is large, because we do so few projects that are the same as others. The advantage of analogous estimating is that it can be done quickly without a large investment of time and resources. The disadvantage is that it is not very accurate, and can suffer (among other things) from optimism bias, where estimated costs are reduced based on the assumption that problems leading to cost increases in analogous projects will be avoided. While that may be true, we frequently discover different problems that will offset any reductions in cost derived from lessons learned from the analogous project, so care needs to be taken when making those kinds of adjustments. For truly new and unique projects, there may not be an analogous one to compare to.

3.1.2 Parametric Estimating

Parametric estimating is similar to analogous estimating, but uses aggregate data from multiple projects to predict costs. For example, if a project being considered will use plastic scintillator, the unit cost of the scintillator used in several other projects might be averaged and multiplied by the amount of needed scintillator to get a better cost estimate than you would get from only one data point. The same thing can be done for labor, other materials, and equipment. Again, for the kinds of projects Fermilab does, finding multiple analogous projects with the same activities that can be compared in a valid way is sometimes not possible.

3.1.3 Three Point Estimating

The three point estimate technique, one example of which is called PERT (Program Evaluation and Review Technique), attempts to increase the estimate accuracy beyond the two techniques above by making three estimates. This technique calculates an estimate based on the most likely, a pessimistic, and an optimistic estimate, for either cost or time. The three are combined, giving more weight (4 times the others) to the most likely estimate. One difficulty with this is ensuring that the three points are actually objective. If not, the weighted estimate and the standard deviation are not going to be meaningful. This analysis is done treating each activity needed to complete the project as independent.

The PERT technique is commonly used in conjunction with CPM (Critical Path Method). In CPM, all the activities are time phased, with understood dependencies and starting and stopping points, so that the longest duration path through them to project completion is identified. Identifying the critical path, and thus the minimum time needed to complete the project is a strength of PERT/CPM. One weakness of PERT/CPM is the treatment of activities as independent, so that resources needed for an activity are implicitly assumed to be available when needed. Overall it is a useful system, as long as it is understood that the subjective nature of activity duration estimates (and associated cost) will not necessarily balance out over a large number of activities. In general, the critical path and near critical path activities will be underestimated, leading to longer project durations than projected.

3.1.4 Bottom Up Estimating

The next cost estimating methodology is the bottom up one used to create a logically constructed schedule of activities that is resource loaded at the lowest activity level. This is what is generally used in generating baselines for Fermilab projects. The bottom up technique is the most accurate, but also the most resource-consuming and expensive way to make a point estimate. As with PERT/CPM, every single activity needed to complete the project is defined, and the dependencies and interfaces are all laid out so a schedule can be constructed. After the total project work is broken down into the smallest work components making up the Work Breakdown Structure (WBS), each component cost is estimated and its basis of estimate (BOE) defined. The reason for breaking the work down to the lowest level is that it allows the cost to be built up from relatively well known, consistently priced things. For example, while the total cost of designing different electronics boards may vary widely, based on the complexity and size of the board, the cost of an hour of a design engineers time should be consistent from board to board. Knowing how long it takes to design circuits composed of some number of component parts, and the number of those parts on the given board lets you build up a cost of the board using multipliers of known quantities. For something as complicated as an electronics board can be, getting that scaling right can be very difficult, and this will be reflected in the estimate uncertainty that is eventually assigned.

For each activity the bottom up cost estimate is built up from a BOE. The BOE uses a standard format for each project, and includes all the information needed to calculate the activity cost. All the individual activities are aggregated to get the project’s cost estimate. While an accurate way to develop a cost estimate, the bottom-up method has the disadvantage that to work, you must understand each activity in detail. When that is not possible, one of the other methods above may save a lot of time and effort, albeit with less accuracy, and a correspondingly large uncertainty in cost and schedule. As with PERT/CPM, a weakness of the bottom-up method is the treatment of activities as independent, so that resources needed for an activity are implicitly assumed to be available when needed.

3.1.5 Structuring the Estimate for EVMS

While not an estimating technique, there is another thing to remember when developing estimates to go into the Resource Loaded Schedule (RLS). A cornerstone of Fermilab projects is that each activity must be defined so that progress can be tracked and measured against what was planned. We do this using the "earned value" technique, which was originally developed by the Department of Defense in the 1960's. To use earned value, the bottom up point estimate is used to provide the "value" of the activity. To use earned value, the project compares the cost of the work performed to the value assigned to it in the point estimate. It measures the value of the work performed while the activity is in progress, and compares the amount of money or time spent on the project or activity with what the estimate predicted. The DOE uses earned value to understand the progress a project is making through a well defined set of indices generated in the comparison of effort or money spent to the value assigned in the cost estimate. Getting the bottom up estimate right makes the earned value technique useful, and structuring your activities and estimates so that the value at each step can be easily understood and compared to the real cost or time is imperative.

In the end, for Fermilab projects, the schedule used for the estimate must reflect the entirety of the project's scope of work, and support all key event milestones. The ground rules and assumptions used to build the cost estimates and schedule are documented in a "Key Assumptions" document, which should include definitions of the project's standard estimating guidelines to be followed. In practice, this means that all required labor, material and procurement types have been identified, and rates and burdens are defined. The applicable managers will be responsible for determining the labor, material, and procurement requirements needed to support the scope of work in their subsystems. Each person or team charged with developing a cost estimate should be given a copy of the Key Assumptions document.

- The Project Manager should review the key assumptions with the project team on a regular basis.
- A standard "Basis of Estimate" methodology and format using guidance from the Key Assumptions document should be used by all people in the project making cost estimates.
- Every task should have an estimate uncertainty that is based on how well understood the estimate is for the exact item being costed, usually based on the design maturity of the activity. Less defined activities can have a large uncertainty, up to 100% or more of the base cost estimate. As the task is better defined the uncertainty usually reduces, following the project's guidelines. Each project will have a percent based multiplier chart they provide to cost estimators. The cost estimate at this point should not include in the base activity or estimate uncertainty funds to cover "risk" events. The contribution to the project cost from risk events is determined by the risk procedure, and is separate from the estimate uncertainty.

- As the project progresses, assumptions may change, and the document needs to be updated and communicated to all people in the project whose estimates may be impacted.

3.2 Making the point Cost Estimate

Each element of the WBS will have a person or group assigned to develop cost estimate. In practice initial estimates are often top down or analogous because the detailed scope is not yet known, and these will ultimately be replaced by bottom up estimates as the project matures. Fermilab projects usually take years from inception to completion, and the point cost estimate done at the lowest level will continue to evolve until the project begins measuring performance using the FRA Earned Value Management System. A goal is to have the estimate as correct for each activity as early in the project as possible. In this section we focus on ways to increase the accuracy of the point estimate, so that the actual cost for the task is as close to the estimate as possible. For all activities that are included in the project scope, a basis of estimate form should be used to develop and document the cost estimate. At Fermilab, there is more than one BOE tool, but they all follow the same process.

There are many questions an estimator can ask to understand the cost estimate and the basis of the estimate. The following lists contain some of the questions the project team should ask itself, along with follow-ups, as they develop the cost estimate.

3.2.1 Questions to Ask While Developing an Estimate

3.2.1.1 Assumptions

1) Are the ground rules and assumptions reasonable? If not, why not? Document your questions and pass them up to the PM, it may be they need revision.
2) Do you understand the assumptions about qualifications and training needed by work performers? Can you be sure the maximally qualified workers will be available to do the work, or will people need training? If they do, that activity needs to be understood, costed, and its schedule impact included. Trained people leaving is a risk, but that possibility should not factor into the point estimate, and should be captured in the risk register instead.
3) Is the assumed size of the required staff reasonable and likely to be available? Initial project plans often include pileups of certain skill sets that are not credible, e.g. the plan calls for implausible short peaks of specific skill sets, or a specific individual worker is overcommitted. These distributions must be leveled as part of the iterative estimating process. Is each work performer assumed to be 100% available? If not, is the efficiency of activity transitions correctly accounted for?
4) Have you assumed personnel resources are 100% productive? A task that you might calculate as requiring 8 hours of labor to accomplish is unlikely to be completed in an 8 hour day by a single individual. Aside from activity transitions, there are still likely to be non-productive moments for people that will increase task durations.

5) Are there likely to be standing army costs? If a project element is delayed, who pays the time for the personnel who are not working?
6) Are there facilities this element depends on that affect the estimate value and that are assumed to be available when needed? Make a list of all those things and document them. Are the costs for all those things included? For space, is there a written agreement for space usage, and an understanding of the support needed, and who will share the costs of maintaining needed equipment that is part of the facility?
7) If there are tooling or facilities dependencies, is the estimator certain of their status? It is not enough to have used the tooling and put it in storage before – the needed tools, etc., should be inventoried and confirmed to be available when the project needs them with their owners. Building new tooling because the old tooling is missing can be expensive. If needed, the estimator or someone must verify that it exists, and get written (or e-mail) commitments from the tooling owner for its use.

3.2.1.2 Scope

1) Have you included management activities in the task, if needed? Include oversight and guidance, unless it is included in a separate management task already. If that is the case, make sure that is entered into the BOE for the management task.
2) Are start up and stop activities correctly estimated? These can be difficult to estimate, and are often incomplete, because people have not really given them the same attention that they give the production steps, particularly the stop activities that you perform as the task completes. Make sure that everything needed to start is included and understood in the work flow, including relocating, refurbishment, and commissioning and calibration of tools and infrastructure. For stop activities, is the equipment just left in place, or does it need to be put into a safe state, de-energized, crated, and stored? Is there time included in the start up and stop activities for documentation generation, review, and final approval?
3) If there are design, safety, or operations readiness reviews needed for start and stop activities, have they been appropriately defined so they can be estimated, including management and review participant time, even if contributed at no cost by others?
4) For testing activities in particular, when estimating the contingency needed, have you included what is required if the test is failed? If so, consider removing that, and putting "failed test" into the risk register, so the exposure in terms of time and money gets examined and tracked where it belongs, and a risk mitigation plan can be developed.
5) What does this task or activity interface to in the project? Are the boundaries and associated costs well understood and agreed to between this element and others so that no needed work scope is missed?
6) Are all other pertinent costs included?

3.2.1.3 Benchmarking

1) Are the costs reasonable when compared to prior actual costs and historical data?
2) Did one person make the estimate, or have multiple people done so? If a single person,

get another independent estimate if possible. If multiple people, how well do their independent estimates compare?

3) Are the learning curves (if applicable) and slopes reasonable for production activities? For production activities, the first unit produced usually takes longer than subsequent ones, as the process is learned and workers become familiar with their tasks. For operations oriented businesses, there is a lot of study of this, and there are some online guides that may be helpful in developing your estimate when multiple units are to be produced.
4) Were appropriate methods used? Is the estimate reflecting analogies and databases that are within the realm of reasonableness, such as technology, platforms, etc?
5) Are the data points/range used as a basis for the cost estimate relevant?

3.2.1.4 Standards and Consistency

1) For labor, is the definition used for FTE conversions to hours understood and used uniformly? Ask the estimator what they used, and correct if needed.
2) Have you confirmed with the project controls personnel that
    a. The correct labor rates were used?
    b. The correct escalation/inflation rates were used?
    c. The correct direct and overhead rates were used?
3) Has the project's standard BOE format been used?
4) Are each element's assumptions consistent with the project's Key Assumptions document?

3.2.1.5 Structure of the Estimate

1) Are costs time-phased over the fiscal years? Both inflated and non-inflated dollars? What is the method of time phasing the point estimate? Is the project schedule consistent with cost estimate schedule used in the phasing?
2) Is the task defined so that its earned value can easily be tracked and understood? For long duration activities, have they been broken up into shorter ones, so that if, for example an LOE activity was estimated incorrectly, you are able to correct instead of carrying a variance for a long time? Do the metrics used to measure progress make sense, and are they easy to understand and measure? If not, it is better to expend effort at the planning stage to find metrics that work well, minimize management time to measure, and are not subjective.
3) For every activity that includes a procurement, should there be a separate series of procurement activities attached? Are the procurement durations well understood, either by analogous experience or communication with procurement, and also consistent with the durations listed in the Key Assumptions document? Is the EV performance impacted by the procurement times? For larger procurements, there can be many hold-ups between when the project thinks it is ready to make a purchase and when a PO is issued. Are all the relevant approvals and associated times understood? If there are DOE, safety, budget office or other approvals needed, is that understood and factored into the estimate? Has management or technical expert time to oversee the

procurement been included in the estimate? If there are site or vendor visits needed, have they been estimated and included?

4) For earned value purposes, have you considered how variances may impact the EV metrics? For example, if it is likely that an equipment delivery or billing may come early or late, with no actual impact to the project, is the task structured so that the “false” temporary variance from that does not skew the metrics? Writing variance reports for activities that will “recover” on their own is a waste of time later in the project, and can divert management attention from real issues. Work with a project controls specialist and reference 12.PM-004.DT-01 “Guidelines for Developing a Schedule”.
5) Did the estimate identify which cost elements were estimated as pass-throughs?
6) Is the activity part of a series to activities, such as conceptual design being part of the overall design, and is the overall design percent complete structured so that the percentage complete for the task is identified, and also the percent complete for the larger activity is well defined? This can be important when approaching construction start, where the design completion percentage is a critical input to determining project readiness.

4 SUMMARY

This supplement to the official cost estimating guide is intended to provide useful context and information that helps projects get the best possible estimate for individual activities and overall. There are many ways for projects to get the cost wrong, and in the end, only one right answer. It is hoped that this supplement helps projects get closer to that right answer.

5 ABBREVIATIONS AND ACRONYMS

BOE	Basis of Estimate
CAM	Control Account Manager
CPM	Critical Path Method
DOE	Department of Energy
EVMS	Earned Value Management System
FRA	Fermi Research Alliance, LLC
GAO	Government Accountability Office
LOE	Level of Effort
OPSS	Fermilab Office of Project Support Services
PERT	Program Evaluation and Review Technique
PRR	Production Readiness Review
PSAD	Preliminary Safety Assessment Document
RLS	Resource Loaded Schedule
SAD	Safety Assessment Document
SR	Safety Review
SRR	System Requirements Review
TPC	Total Project Cost