Assuring Software Cost Estimates: Is it an Oxymoron?

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Abstract

The software industry repeatedly observes cost growth of well over 100% even after decades of cost estimation research and well-known best practices, so “What’s the problem?” In this paper we will provide an overview of the current state of software cost estimation best practice. We then explore whether applying some of the methods used in software assurance might improve the quality of software cost estimates. This paper especially focuses on issues associated with model calibration, estimate review, and the development and documentation of estimates as part of an integrated plan.

1. Introduction

The problems associated with inaccurate software cost estimates are well documented. Early lifecycle effort estimates can be inaccurate by up to 400% [1, p310]. In a study of NASA software development projects conducted in the late nineties, the most frequently identified cause (71%) of cost overrun with the largest impact (35% contribution to observed cost growth) was basic failures in planning, estimation & control [2]. In the worst case, over-running projects are canceled, resulting in the waste of development efforts. For example, in 2003, NASA canceled the CLCS (Check Out Launch Control System) project after spending hundreds of millions of dollars on software development. The project was canceled after the initial estimate of $206 million was increased to between $488 million and $533 million. Upon cancelation, approximately 400 developers lost their jobs [3].

These problems continue even after years of research on cost estimation techniques, the development of sophisticated cost models [1], the creation of cost related professional societies and certification programs for professional cost estimators [4]. Many companies have defined requirements, cost processes and standardized templates to address cost estimation problems. In spite of these contributions to defining Software Estimation Best Practices (BP), the cost estimation community continues to struggle with producing good cost estimates. This seems to be even more of an issue in the aerospace and high tech industries. One contributor to such inaccuracies is that software engineers and managers continue to perform bottom up estimates with little or no data to support their assumptions and little or no consideration for risk and uncertainty [5]. Software cost estimation is not as difficult as theoretical physics or rocket science so, given the technical aptitude of those within the aerospace and high technology industries, one would think that the community would be able to do a better job of cost estimation. This paper explores the contention that (1) many BPs exist but are simply not applied in a consistent manner and (2) the accepted set of cost estimation BPs that does exist, does not completely address the entire cost estimation life-cycle. This paper offers a more comprehensive cost estimation life-cycle and an approach for assuring that BPs and associated activities are followed.

2. State of Current Practice

Software cost growth may occur for several reasons, including requirements changes, new technologies, optimistic heritage assumptions, simultaneous hardware development provided by multiple partners, basic poor planning practices [2, 6], miss application of methods, and corporate ‘strategic-pricing’ with hopes of profiting on follow-on change requests. Researchers have mostly focused on issues associated with errors in estimation and often seek to identify better estimation methods. Such efforts have resulted in varying levels of support for approaches such as analogy methods [8], nearest neighbor methods.
and regression models [9] and regression models [1, 10, 12]. Although, more recent research has proposed support for hybrid methods [11]. Cost Practitioners have focused on issues associated with the use of regression models [10], validation of model performance [13] and estimation handbooks. Such estimation handbooks typically describe the basic characteristics of effective estimating which include clear identification of task, broad participation in preparing estimates, availability of valid data, standardized structure for the estimate, provision for program uncertainties, recognition of inflation, recognition of excluded costs, independent review of estimates, and revision of estimates for significant program changes [7, 14, 15, 16]. All of the listed methods and activities should be considered software estimation BP.

3. Cost Estimation Best Practices

The following is specific list of software cost estimation Best Practices derived from the reference books, handbooks and research papers discussed above [1, 7, 9, 11, 12, 13, 14, 15, 16] combined with material from the NASA JPL Software Cost Estimation Class [17] the International Society of Parametric Analysts Certification Class [4].

Establish a cost estimation infrastructure

These practices make estimation repeatable, consistent, and provide the basis for objective data driven estimates.

1. Develop and maintain a documented estimation process
2. Establish a tailorable standard cost structure for all projects
3. Develop and maintain a cost database that captures the organization’s history. The database should include
   a. effort and cost actuals
   b. history of estimates and budgets over the lifecycle of a project
   c. key planning parameters such as software size, requirements counts, cost model inputs
   d. planned schedule dates for major milestones
   e. defects counts

4. Develop and maintain cost models that are regularly tuned and validated against actuals
5. Peer review on a periodic basis

Performing the Estimate

These practices enable objective estimates that address the inherent uncertainty in a cost estimate, especially when made during the early stages in the life-cycle.

1. Clearly define and documented the scope of effort
2. Determine the size of software
   a. Most common sizing metrics are lines of code, function points, software modules and requirements
   b. Be conservative with reuse assumptions
3. Base estimates on data whenever possible
4. Develop an integrated estimate which incorporates technical scope, high level decomposition and a schedule
5. Use multiple estimates which typically consists of
   a. bottom up estimate
   b. model based estimate
   c. system/mission level analogies
6. Incorporate model assumption and uncertainty by estimating a cost distribution
7. Identify and include risks in the estimate
8. Review and peer-review the estimate
9. Re-estimate when changes occur and at major milestones

Document the Estimate

These practices make an estimate defensible, traceable and updatable.

1. Maintain information in an electronic form that can be easily modified
2. Document the basis of estimate (BOE), which should include
   a. Statement of Work and Scope
   b. Work Breakdown Structure (WBS) with associated dictionary
   c. Effort estimates with supporting assumptions
   d. Planning estimates with supporting assumptions
   e. Supporting model estimates and analogies
   f. Schedule
   g. Procurements
   h. Acquisition approach (if applicable)
   i. Cost estimates
   j. Significant cost and risk drivers
   k. Risk items, issues, and/or any known liens

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\(^2\) As an aside if one were to focus on estimation in the construction industry or for hardware, there would be common elements but also differences as estimation for different types of projects and industries presents different opportunities and risks.
**Monitoring Performance**

These practices provide baseline and trend indicators of performance. They also identify areas of weakness, the need for process improvement and impact measures.

1. **Track performance**
   a. Define a set of metrics for monitoring estimate accuracy and budget growth
2. **Monitor key assumptions and planning parameters such as sizing metrics.**

What is not addressed directly here is the issue that all too often budgets are set while minimizing or even ignoring the estimates of the software teams or organizations. This is partially addressed by 15a, which enables monitoring estimates and budgets against actuals and would provide objective data when unrealistic budgets are a systemic problem in an organization.

**4. What is Software Assurance**

Given the paradox of maintaining a reasonable industry standards and BPs for performing software cost estimation and yet repeatedly producing unreasonable cost overruns and estimation inaccuracies, one should consider whether or not the software cost estimation BPs are actually being implemented. Efforts associated with assuring that such software cost BPs and standards are followed can be borrowed from the Software Assurance community and its methodologies for assuring software during the software development process. This paper suggests that key philosophies and techniques found within the discipline of software assurance, if applied to software cost estimation efforts, could help to produce higher quality and more reliable software cost estimates. Software Assurance techniques have been proven to increase the quality and credibility of software products [18,21]. Just as software assurance techniques help to better software development efforts and the usefulness of software products, these same software assurance techniques can be extrapolated to increase the quality and credibility of software cost estimation efforts. This section describes some of the fundamental principles of software assurance and offers suggestions as to the specific techniques that could be applied to software cost estimation activities.

Software Assurance is the engineering discipline that ensures quality is built into software processes and products and that the software products operate safely. The NASA, agency-level NASA Software Assurance Standard defines Software Assurance as the planned and systematic set of activities that ensure that software life cycle processes and products conform to requirements, standards, and procedures. For NASA this includes the disciplines of Software Quality (functions of Software Quality Engineering, Software Quality Assurance, Software Quality Control), Software Safety, Software Reliability, Software Verification and Validation, and IV&V [20]. Each sub-function within the over-arching discipline of Software Assurance contributes to identifying and/or mitigating risks and builds credibility into the software development process, such that quality software processes and software products are developed. Although it is recognized that how Software Assurance methodologies are performed may differ from one corporate culture to the next, many government agencies and corporations have developed at least some form of Software Assurance or quality control practices for software development. This paper will mostly focus on the Software Assurance methodologies used at NASA and how these methodologies could be applied to improve the quality of software cost estimates. It is recognized that at NASA, the discipline of Software Assurance includes the sub-disciplines of Software Safety, Software Reliability, Software Quality and Software Verification. However, this paper will mostly offer parallels between Software Quality Assurance and how it can be applied to software cost estimation.

**Software Quality**

Software Quality Assurance implements techniques to make sure that that software development products and processes are in conformance with established procedures, appropriate for the project of interest. For example, Software Quality Assurance engineers emphasizes that specific quality plans are in place for each software development effort. Such plans may include configuration management plans, risk management plans, software management plans, software development plans, etc. These plans are to be adhered to throughout the software development lifecycle. Typically, the Software Quality Assurance engineer will establish working lines of communication between the software systems engineer and project management leadership to ensure that any higher-level standards and BPs are flowed down to the project-level and that appropriate project-level plans are followed. Another key attribute of the software quality assurance effort is making sure that software requirements are clearly written, traceable and verifiable. To this extent quality assurance engineers review all plans, procedures, requirements, design, verification documentation, reports, schedules, and
records and assess them for risk to the project and impact against the quality of the software being developed. Formal testing events and peer reviews are typically attended by software quality assurance personnel who serve as independent assessors of activities. Software quality audits may be planned (or initiated randomly) to assess the project's adherence to product quality standards and procedures. Software quality assurance engineers assure that software quality metrics have been defined and are being used to ensure that data trends associated with risk areas are reported and mitigated as necessary. Software Quality Assurance engineers assure that software is tested appropriately and verified for compliance with functional and performance requirements. Problem reporting is of high interest to software quality assurance engineers. Likewise, portions of the software that are deemed significant and may add additional risk to the development effort are reported to key decision-making boards and panels. To this extent the role of the Software Quality Assurance engineer is to assure that software is being developed according to the given standards and procedures predefined by the agency and project of interest. These processes and procedures help to establish control, consistency, repeatability, maintenance, sustainability, traceability, and trend analysis. These attributes help to establish robust software development efforts and build confidence that the software being developed will perform successfully and safely.

Example Design Inspection Walkthrough Checklist

There are several checklists that can be used to perform quality assurance functions during the software development lifecycle. Figure 1 provides an example of a Checklist, used to assure that software design is developed within the context of a quality standard. This checklist was developed by the Software Engineering Division at Goddard Space Flight Center, such that during a design walkthrough, the software might be evaluated for Completeness, Suitability, Correctness, Simplicity, and Quality. It is important to note here, that this checklist was developed by the software engineering division, and not by the Quality Assurance organization, which is a positive sign of internal accountability by the Software Engineering organization and the Software Assurance organization. Additional independent Software Quality checklists may be offered as examples in future papers. The software quality assurance organization at GSFC would use checklists such as this to perform compliance assessments against the software design.

<table>
<thead>
<tr>
<th>1 Completeness – Specification of design is to the appropriate level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidance: Not all may be applicable for a particular system (e.g., not all systems will need to consider COTS), but each check should be considered.</td>
</tr>
<tr>
<td>Review Requirements Traceability Matrix to ensure coverage of all requirements</td>
</tr>
<tr>
<td>Ensure coverage of:</td>
</tr>
<tr>
<td>Real-time requirements</td>
</tr>
<tr>
<td>Performance issues (memory and timing)</td>
</tr>
<tr>
<td>Spare capacity (CPU and memory)</td>
</tr>
<tr>
<td>Maintainability</td>
</tr>
<tr>
<td>Understandability</td>
</tr>
<tr>
<td>Database requirements</td>
</tr>
<tr>
<td>Loading and initialization</td>
</tr>
<tr>
<td>Error handling and recovery</td>
</tr>
<tr>
<td>User interface issues</td>
</tr>
<tr>
<td>Software upgrades</td>
</tr>
<tr>
<td>Software re-use and modifications</td>
</tr>
<tr>
<td>COTS</td>
</tr>
<tr>
<td>All inputs and outputs</td>
</tr>
<tr>
<td>Clearly and correctly identify interfaces</td>
</tr>
<tr>
<td>All functions clearly and accurately described in sufficient detail</td>
</tr>
<tr>
<td>All interfaces clearly and (appropriately) precisely defined</td>
</tr>
<tr>
<td>Adequate data structures defined</td>
</tr>
<tr>
<td>All error codes documented</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 Suitability – The design itself is good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviations from the requirements are documented and approved</td>
</tr>
<tr>
<td>Assumptions are documented</td>
</tr>
<tr>
<td>Major design decisions are documented</td>
</tr>
<tr>
<td>The design is expressed in precise unambiguous terms</td>
</tr>
<tr>
<td>Dependencies on other functions, operating system, hardware etc. are documented</td>
</tr>
<tr>
<td>The design follows notational conventions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Correctness – The design will lead to good software</th>
</tr>
</thead>
<tbody>
<tr>
<td>The logic is correct</td>
</tr>
<tr>
<td>Memory and timing budgets are reasonable and achievable</td>
</tr>
<tr>
<td>Error messages are helpful and understandable</td>
</tr>
<tr>
<td>The design is understandable (i.e., easy to read, to follow logic)</td>
</tr>
<tr>
<td>It is maintainable (i.e., no obscure logic)</td>
</tr>
<tr>
<td>It is testable</td>
</tr>
<tr>
<td>It is consistent (i.e., program flow and data format match between sending and receiving components/software units)</td>
</tr>
<tr>
<td>It is cohesive (i.e., proper groupings of related components/functions)</td>
</tr>
<tr>
<td>It is mutually suspicious (i.e., the components/software units check each other for errors in parameters or other exchanged data)</td>
</tr>
<tr>
<td>COTS and GOTS have been verified to fulfill their intended purpose</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4 Simplicity – Complexity no more than necessary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have alternate design approaches been evaluated and the optimum chosen?</td>
</tr>
<tr>
<td>User interface/screens have been verified with end users?</td>
</tr>
<tr>
<td>Are there minimal requirements TBD's?</td>
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</table>

Figure 1: Design Inspection Walkthrough Checklist
5. How Can Assurance Methods be Applied to Software Cost Estimates

NASA maintains agency level standards/requirements for both Software Engineering as well as Software Assurance. NASA programs and projects must abide by these standards when developing software, or seek relief in the form of a waiver or deviation. These standards impose requirements on procedures, architecture efforts, implementation activities, and other related tasks used to acquire, develop, assure, and maintain software for NASA programs. The Software Engineering agency-level requirements are designed to be a minimum set of requirements to protect the Agency’s investment in software engineering products and to fulfill its responsibility to the citizens of the United States of America [21]. Likewise NASA agency-level Software Assurance requirements were developed in order to establish a common framework, including generic quality procedures for the software assurance process in support of all life cycle processes, establish and support the cooperation of various groups who are conducting different aspects of the total software assurance process, support and utilize the independent reporting structure required for NASA safety, reliability, and quality processes, and define software assurance activities and tasks to meet the objectives of software assurance [18]. These two high-level agency standards, provide the overall context for which software engineering and software assurance should be performed. Together, the standards compliment each other in order to comprehensively address the development processes/practices as well as to assure that those processes/practices are fulfilled according to the established plans. This approach can be adopted within the community of software estimators. The following text offer parallels between Software Assurance methodologies and how they could be applied to Software Cost Estimation.

One of the paramount functions within Software Assurance is ensuring that guidelines, standards, processes and procedures are documented and followed. Without the appropriate level of oversight, software development efforts may loose configuration control, traceability, sustainability and maintainability. Software Assurance engineers could extend these very same methodologies to ensure that software cost estimation processes and standards are followed. Software Assurance personnel could maintain configuration control and track any changes to the estimation process. Software Assurance personnel could manage any tailoring of estimation standards or deviations from the defined process as well as facilitate any impact analysis to be performed on any major changes to the process. This approach would enable the appropriate amount of independent over-sight and in-sight, by extending typical software assurance functions to include assurance of software cost estimation efforts.

Software assurance requirements typically require traceability between the software engineering requirements and areas of concern related to safety, quality, and reliability. For example, NASA software developments require that safety critical software requirements are clearly defined as safety critical and are traceable to hazard analysis. To this extent, if there are changes to any requirements that have safety implications, the appropriate parties are made aware of such changes. This requirement traceability is required to ensure that there is an awareness of how the such software changes may impact the over all safety or reliability of the system. Likewise, one might want to trace specific software cost estimates to particular areas of the software development activity, such that any metrics anomalies can be clearly identified and isolated for the appropriate corrective action.

Software Assurance standards typically require the proper training and skill levels for those developing software, testing software and implementing software. This is especially important in the case of safety critical or mission critical software. This training emphasizes the idea that those developing software should have attained a given level of aptitude or one might expect the resulting software quality to be compromised. Likewise, operating software within a testing environment without the appropriate skill level to do so, could be detrimental to the testing exercise, could impose damage on the system and even more severe, could cause loss of human life. As a result, software assurance engineers levy requirements that ensure software developers, testers and operators are properly trained.

The essence of such training requirements could be applied to personnel performing software cost estimations. The person performing the software cost estimate should be well trained within the industry and discipline of software development for which the estimate is being performed. In other words, the software cost estimator should be familiar with the development for which he/she is estimating. Often times, the cost estimators work within completely different business units or organizations from which the software is being performed. The cost estimator should at least have some domain knowledge of that which is to be estimated. Maintaining the appropriate level of training also applies to understanding what requirements and standards the software developers will need to follow. For example, NASA standards invoke a variety of requirements depending on if the
mission of interest is a human-rated mission, robotic-
space mission of high importance or a low-risk
experiment. Maintaining a working knowledge of the
software standards and requirements can be ensured
via the proper training of the software cost estimators.
Lastly, training applies to the proper use of any tools
used to perform the software cost estimates. Assurance
engineers should ensure that software cost estimators
are well and trained on the tool being used and that
they are knowledgeable enough on that specific tool to
use it properly.

Software Assurance engineers are typically
involved with ensuring that algorithms and quantitative
models used within the flight and ground software
meets the intended need of use. Software Assurance
engineers ensure that such algorithms and models are
implemented correctly and are controlled properly.
There are many problems that can result from loose
control and open manipulation of algorithms in
spacecraft software. Software assurance engineers
support the development and planning of such
algorithms to ensure that processes are adhered to and
testing of algorithms is sufficient. These same
software assurance principles should be applied to
software cost estimation efforts involving quantitative
modeling and manipulation of estimation inputs.
Software estimation tools use a variety of different
algorithms and modeling assumptions, some of which
can be manipulated by the user. Manipulation of
estimation modeling algorithms and or the use of
equations for estimating cost should be verified and
controlled to the appropriate level of intended use by
Software Assurance engineers. Software Assurance
engineers could independently verify cost models of
interest, ensure cost models are in synch with software
cost estimation standards and regulatory documents,
and ensure models are used within the context of their
purpose. When cost estimate distributions are
performed, Software Assurance engineers should
maintain objective evidence of distribution results for
future references and any potential distribution
function re-runs.

Software Assurance engineers typically support
software development peer reviews activities in order
to gain necessary levels of insight needed to perform
software assurance functions as well as to ensure that
such peer reviews are being conducted according to the
standards. This function can be extended to have
Software Assurance engineers participate in cost
estimation reviews.

The use of historical databases can be an
enormous help to software cost estimators. However,
when using historical databases it is important to make
sure that the information in those databases are verified
for the intended use and any known areas of concern
are addressed prior to use. Databases may include
information from previous projects, however
assumptions used for one project may be very different
from another project. Software Assurance personnel
could help to review software cost databases for
consistency with software standards, maintain
configuration control and track any major changes with
database and audit estimation efforts for proper use of the
database.

Software Assurance Engineers and Software
Engineers use metric data to expose trends that may
lead to problematic portions of the software or risk
areas of interest. Metrics should be kept when
performing software estimates and compared to actuals
throughout the life of the development activity for
similar reasons. Such trend data can help to uncover
problem or risk areas associated with cost overruns or
inaccuracies of a particular group or functional area.

Software cost estimators will typically develop
some form of assumption regarding the size of the
software. It may help to have Software Assurance
personnel provide an independent verification of the
sizing estimate, check inputs and assumptions for
sizing activity, and identify any areas of concern or any
considerations that may not be taken into account by
sizing tools. This would offer sort of an independent
sanity-check on the sizing estimate and provide the
estimators with multiple data points on which to base a
final estimate. Software Assurance personnel could
help vet the software cost estimate approach with
personnel at the working level, who may be
responsible for performing the actual software
development effort. This would help to ensure that the
expectations associated with the software cost
estimates are within reason with the personnel
expected to perform the actual software development
activities.

Software Assurance engineers are involved with
every major milestone review throughout the software
development lifecycle. The intent is that certain
activities need to be reevaluated at least at every major
milestone. Likewise, Software Assurance engineers
could review software cost estimates at major
milestone reviews in order to compare actuals to the
initial estimates. This comparison would help ensure
that the quality of the estimation practices are not
degraded as the project moves forward and it would
help to ensure that any new assumptions have been
taken into account.

Example Sizing and Heritage Checklists

Software Quality checklists are used as tools for
identifying key items of interest during assurance
activities. Similar checklists can be used improve
software cost estimate quality. Figure 1, provides a notional software cost estimation checklist. Two of the most important cost drivers are the estimates of the size of the system and the amount of reuse (heritage) from previous systems. Given the level of importance that these two cost drivers impose on estimation efforts, a checklist approach might be especially beneficial. These two areas of interest are often root cause contributors for software estimation inaccuracies and cost overruns. Notional examples of a Software Lines of Code (SLOC) Determination Quality Assurance Checklist and a Consideration for Heritage Quality Assurance Checklist that could be used for Software Cost Estimation purposes are provided in Figure 2 and Figure 3.

<table>
<thead>
<tr>
<th>Software Size Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Source of analogy reference (be specific):</td>
</tr>
<tr>
<td>2. Why is this analogy appropriate?</td>
</tr>
<tr>
<td>3. Is the code count consistent with institutional or project counting rules?</td>
</tr>
<tr>
<td>a. Was a code counter used?</td>
</tr>
<tr>
<td>b. Delivered vs written code?</td>
</tr>
<tr>
<td>c. Types of source lines included (Executable</td>
</tr>
<tr>
<td>i. Nonexecutable</td>
</tr>
<tr>
<td>ii. Declarations</td>
</tr>
<tr>
<td>iii. Compiler directives</td>
</tr>
<tr>
<td>iv. Comments</td>
</tr>
<tr>
<td>v. Blank lines</td>
</tr>
<tr>
<td>4. Are size adjustment rules documented</td>
</tr>
<tr>
<td>5. Are size adjustment rules reproducible</td>
</tr>
</tbody>
</table>

Figure 2: Example Software Size Checklist

<table>
<thead>
<tr>
<th>Software Heritage Checklist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Project/System</td>
</tr>
<tr>
<td>2. Software Element Name (Modules, CSCI, Subsystem)</td>
</tr>
<tr>
<td>3. Software Element Description</td>
</tr>
<tr>
<td>4. History of Heritage Software</td>
</tr>
<tr>
<td>a. Software Class of Heritage Module (Class A, B, C)</td>
</tr>
<tr>
<td>b. Has the software element been successfully reused on a previous project?</td>
</tr>
<tr>
<td>c. Was the Heritage Module designed to be reused (Yes, No)</td>
</tr>
<tr>
<td>d. Do the following artifacts exist</td>
</tr>
<tr>
<td>i. Design</td>
</tr>
<tr>
<td>ii. Unit Test</td>
</tr>
<tr>
<td>iii. Open Defect Reports</td>
</tr>
<tr>
<td>iv. Record of previous failure reports exists</td>
</tr>
<tr>
<td>5. Heritage Type (Reused, Reengineered)</td>
</tr>
<tr>
<td>6. New Module Software Class (Class A, B, C)</td>
</tr>
<tr>
<td>7. Similarity of Use Case with the heritage element</td>
</tr>
<tr>
<td>8. Is the heritage software compatible with current requirements</td>
</tr>
</tbody>
</table>

Figure 3: Example Software Heritage Checklist

6. Lessons Learned from Software Process Assessment Methods at JPL

While the exact method proposed in this paper has not been performed there are two JPL activities being performed that provide some insight into current practice and the usefulness of assessment type methodologies. The process assessment activities that are performed, are the Tailoring Record (TR) used by the engineering divisions and what is known as PPQA or Product and Process Quality Assessments which are typically performed by the software quality assurance organization. The TR is a record of what projects plan to do and PPQA provides a record of what projects are actually doing relative to their intent. The TR captures what the team says they will do based on their self report while PPQA is based on an independent assessment of an artifact [23].

The TR compares the processes used on an individual software project to the institutional Software Development Standard Processes (SDSP). The TR is required because the JPL processes are highly tailor able so that they can be efficiently used by a wide range of software, which differ in size, domain and required reliability. The TR is generated early in the lifecycle of a project or task and ultimately assists the initial writing of software management and development plans. The SDSPs consist of 523 sub-activities in 21 processes3 [24]. We only review those processes that are being utilized by the project. For example new flight software developments engage all process while projects in maintenance may only engage the implementation and validation processes. Over the last three to four years approximately fifty TRs have been completed. The initial TRs took 6 to 16 hours to complete. Today as we have learned to make the review process more efficient it only requires 4-6 hours to complete a TR. This indicates that when first starting the TR process it took 1 to 2 minutes per sub-activity while today it requires 0.5 to 0.8 minute per sub-activity. The JPL estimation process has 14 sub-activities which correspond to the Best Practices 6-14 and only at a very high level to Best Practice 16 (See Section 3). As currently written the estimation process takes 7 to 11 minutes to review. At JPL the primary non-performance in the estimation process is documenting the estimate, which is Best Practice 16. To more precisely reflect the Best Practices identified in this paper the number of sub-activities in the current JPL process would need to be increased in length from 50 to 100%. Virtually all the changes would be in the

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3 Excludes the Software Acquisition Management process.
document BOE activity. This suggests that it would
take a minimum of 10 minutes to a maximum of 22
minutes to review the expanded process.

PPQA provides objective insight into how well a
project is adhering to its planned processes and to the
standards it has adopted for its work products. Tasks
are required to develop an audit plan, which includes
evaluation of processes and products based on the
organizations' quality objectives and following the JPL
PPQA process. While PPQA can be conducted by line
management with appropriate training and oversight, a
large percentage of these activities are performed by
JPL's Software Quality Assurance (SQA) organization.
This evaluation method is more analogous to the
assessment method proposed here. Fortunately, very
recently the software assurance organization has
started to experiment with recording time estimates for
completion of different assessment activities. We have
small number of observations which indicate it requires
from 12 to 20 minutes per page with a 15 minute
average. The documents reviewed did not include a
planning or BOE document but included
requirements, architecture and design documents
along with some release documents. These documents
ranged in length from 15 to 31 pages with an average
length of 19 pages. At JPL BOE's (Best Practices 6
through 16) are typically in slide form not paper style
documents. Slide pages are overall less dense than a
paper pages. One of the more complete BOE's at JPL
was 20 pages with 9 pages of back-up. This suggests
an assurance style review would take from 2.5 hours to
7 hours. It would be expected that this would be
conducted in preparation to a cost review where the
'correctness' of the estimate would assessed. To date
no direct PPQA assessments have been performed on
software cost estimates. In the last 2.5 years there has
been one finding against estimation that arose during
an assessment of a software management plan.

7. Conclusion and Next Steps

Over the last three decades there have been
extensive advances in the techniques used to estimate
and monitor software development cost. In spite of
these improvements in quantitative methods there
remains a struggle to complete projects within the
planned time and schedule. The essence of this paper
is that the community understands the practices and
procedures that need to be performed in order to do
better cost estimation, it just needs to follow through
and do it! One mechanism to increase the use of these
known BPs is to use the well-established quality
assurance methods of independent audits. This can be
performed by the software assurance organization but
can also be performed by the engineering or business
divisions within an organization. Clearly, this paper
does not address all of the causes of software cost
growth, yet perhaps adding an assurance function to
the software cost estimation effort will reduce the
influence of those causes associated with undisciplined
and even unprofessional practices.

Future follow-on efforts of this paper include
development of a more complete set of assurance
checklists, followed by a pilot program to implement
these checklists on a NASA project. As part of the
pilot study, methodologies would be established to
assess and measure the use of the assurance approach
and the associated impact on the project's conformance
with software cost estimation best practices.

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