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Technology Estimating 2: A Process to Determine the Cost and Schedule of Space Technology Research and Development

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Abstract

As a leader in space technology research and development, NASA is continuing in the development of the Technology Estimating process, initiated in 2012, for estimating the cost and schedule of low maturity technology research and development, where the Technology Readiness Level is less than TRL 6. NASA's Technology Roadmap areas consist of 14 technology areas. The focus of this continuing Technology Estimating effort included four Technology Areas (TA): TA3 Space Power and Energy Storage, TA4 Robotics, TA8 Instruments, and TA12 Materials, to confine the research to the most abundant data pool. This research report continues the development of technology estimating efforts completed during 2013-2014, and addresses the refinement of parameters selected and recommended for use in the estimating process, where the parameters developed are applicable to Cost Estimating Relationships (CERs) used in the parametric cost estimating analysis. This research addresses the architecture for administration of the Technology Cost and Scheduling Estimating tool, the parameters suggested for computer software adjunct to any technology area, and the identification of gaps in the Technology Estimating process.

Introduction and Background

This research covers the period from July 2013 to February 2014 and was a continuation of the work to implement a capability for providing a technology estimating process, initiated in 2012, and sponsored by the NASA Office of Evaluation, Cost Analysis Division (CAD) in collaboration with the Space Technology Mission Directorate, and Game Changing Development Program Office.

The research goal was to improve NASA’s ability to estimate the cost of technology research and development for low maturity technologies. This technology estimating research evolved by selection of critical parameters that were expected to influence the cost of a technology research and development, a continuation of collecting actual data for completed technology efforts, and then conducting mathematical and statistical analyses to generate cost estimating relationships between the parameters and use of these data in an analysis to determine the cost and schedule of technology development for Technology Readiness Level less than 6.⁽¹⁾

Recognizing that NASA currently has 14 Technology Roadmap Areas, the effort for constructing a database of completed projects for the full 14 Technology Areas was beyond the scope of the research. Strategically, only a few select technologies were to be investigated and these included Technology Areas (TAs): Space Power (TA03) and Energy Storage, Robotics (TA04), Instruments (TA08), and Materials (TA12), as these provided the highest number of potential projects for use in evaluating the parameters considered, and were determined to be good candidates for fulfillment of data acquisition.

A diagram, Figure 1, was prepared to map the continuation of the procedural process followed during the research project and includes a series of activities, parallel analysis, workshops, an interim review, and internal reviews within the NASA Cost Community to continue with the identification of issues and the development of the Technology Estimating Research project. This structure facilitated the necessary NASA Cost community input and acceptance of the process, and thereby allowing a high profile platform for the internal review. More specifically, the process was adapted to include dual processes in the Technology Cost and Schedule Estimating (TCASE) tool.

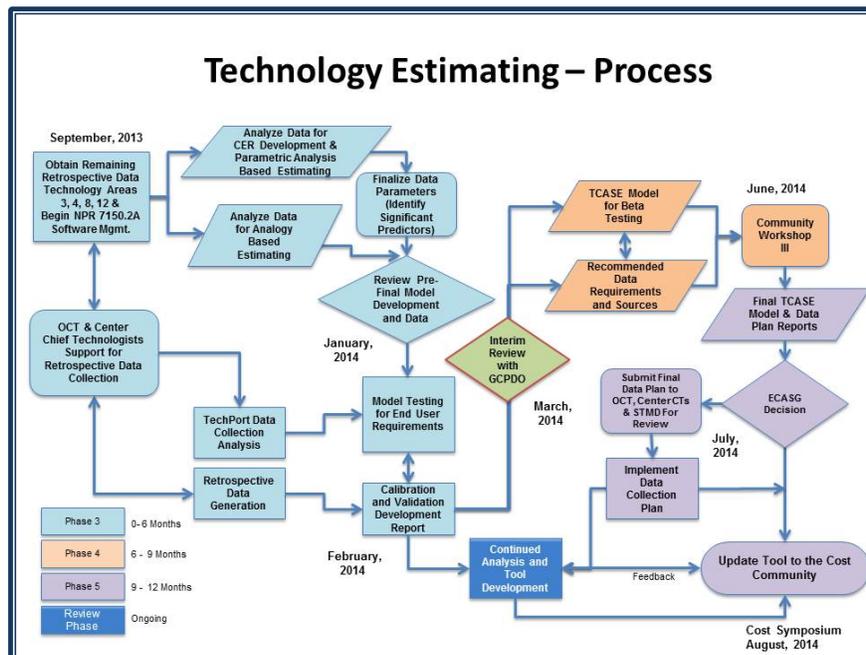


Figure 1. Technology Estimating Process Diagram, 2013-2014

Data is critical for the Technology Estimating process. Obtaining this data in the form of cost estimating parameters for each of NASA's R&D projects was considered fundamental to the Technology Estimating process and continued development of the Technology Cost and Schedule Estimating (TCASE) tool. NASA's *TechPort* was identified in this research as the most reliable resource and repository for this technology estimating data. *TechPort* is a portal developed by NASA, as a software system to capture, track, and manage NASA's portfolio of technology investments.

Evaluation of Technology Estimating Parameters

The Technology Estimating research conducted during 2012-2013 determined that the best method suited for use as an estimating method for estimating technology research and development (R&D) was the parametric analysis. The research then focused on defining those parameters, which best represent the drivers for cost and schedule in technology R&D and ultimately incorporating those parameters in the parametric analysis as Cost Estimating Relationships (CERs).

Parametric estimating is a statistical relationship method developed between historical costs and program, physical, and performance characteristics. The parametric method relates cost to one or more technical, performance, cost, or program parameters, using a statistical relationship. The goal of parametric estimating is to create a statistically valid cost estimating relationship using historical data.⁽²⁾ The foundation on which parametric estimating is based is the use of CERs by which the analysis is performed.

An analysis was conducted for approximately 600 project records in only four of the 14 Technology Areas (i.e., TA03, TA04, TA08, and TA12) as a test bed, and to reduce the set of technology project data parameters to those key parameters determined to be most informative in terms of predicting target variables for both total project cost and total project duration. This reduction in the parameter set number makes the data collection more practical. In addition, the reduced number of parameters provides for increased efficiency and affords a practical step in the process for creating a predictive model for cost & duration.

The analysis of the historical technology project data in the TCASE database was also performed to help determine which parameters were believed to be most useful for cost and duration prediction. As a predictor, the parameter must be a schedule and cost driver. As a driver, a parameter that tends to increase or decrease schedule/cost, or has been identified to be highly correlated with schedule/cost. To qualify as a cost driver, a parameter must be a significant predictor of schedule/cost at least in the statistical sense.

The methodology used in the analysis included an examination of each technology project data parameters on a one-at-a-time basis. First, each parameter was taken and then the set of 600 plus data records were subdivided by all levels of that parameter. Next, a statistical test was performed to determine whether there was a significant difference, i.e. beyond simple randomness in the data, between the distributions of cost and/or duration for projects in these subdivided groups. The tendency of a parameter to subdivide the full dataset into groups with significantly different costs and/or durations was evaluated to indicate if a parameter was a good choice for use in predictive modeling. The statistical testing described here was just one of several factors that may ultimately determine which technology project data parameters were to remain in the final set.

The statistical analysis used for the examination of the parameters was the Kruskal-Wallis one-way analysis of variance. This statistical method of analysis is a non-parametric test that is applied much like the Analysis of Variance (ANOVA) test.⁽³⁾ Non-parametric means that this test does not assume the data to be tested conform to any particular distribution shape or characteristics, e.g. does not require input data to adhere to a normal distribution. The ANOVA test is best suited for test data that has been found to

be approximately normally distributed (although the test is robust to violations of this assumption as long as the sample size is large). The TCASE data tested was not always normally distributed. Kruskal-Wallis has no such assumption of normally distributed test data and is non-parametric.

Where the Kruskal-Wallis test did not apply, the Two Sample t-Test was used for the parameter analysis. In cases where the parameter were dichotomous, e.g. Yes/No, Push/Pull, etc., the t-test was determined to be an appropriate method and will return identical or nearly identical results when compared with the more involved tests such as ANOVA. The analysis was performed to reveal those parameters when considered individually, partition the full sample set into groups with statistically significant distributions of project cost and/or duration. In statistical terms, the null hypothesis is a condition where the distributions are the same across all levels. The alternative hypothesis is that the distributions are not the same.

In summary, the statistical test results presented in Table 1, although interesting, were not predisposed to fulfill the notion that a useful regression model could be identified or a parametric model could be created using these data. The analysis indicates that the parameters identified as “rejected null hypothesis” could potentially contribute to a future parametric model that is statistically valid and well-conceived.

**Table 1
Parameter Data Analysis Results**

Parameter Name	Parameter Type	Sample Size (cost; duration)	Test Type (p-value = 0.05)	Test Outcome Target =			
				COST	DURATION		
				Reject Null Hypothesis	Failed to Reject	Reject Null Hypothesis	Failed to Reject
Technology Area	Categorical (4 levels)	n = 620; 583	Kruskal-Wallis	✓		✓	
Technology Readiness Level	Categorical (27 levels)	n = 541; 535	Kruskal-Wallis	✓		✓	
System Hierarchy Level	Categorical (5 levels)	n = 609; 573	Kruskal-Wallis	✓		✓	
Lead NASA Center	Categorical (8 levels)	n = 166; 139	Kruskal-Wallis	✓			✓ (a)
RD ³	Categorical (5 levels)	n = 101; 99	Kruskal-Wallis	✓		✓	
Hardware vs. Software	Categorical (5 levels)	n = 55; 54	Kruskal-Wallis		✓		✓
Team Experience	Categorical (4 levels)	n = 53; 52	Kruskal-Wallis		✓		✓
AD ²	Categorical (9 levels)	n = 53; 52	Kruskal-Wallis		✓		✓
Unplanned Events	Dichotomous	n = 44; 43	Two Sample t-Test		✓		✓
Technology Push vs. Pull	Dichotomous	n = 63; 62	Two Sample t-Test		✓		✓
Evolutionary vs. Revolutionary	Dichotomous	n = 52; 51	Two Sample t-Test		✓ (a)		✓
Facilities and Infrastructure	Dichotomous	n = 49; 49		N/A (could not test)			
Budget Constraints/Disruptions	Dichotomous	n = 46; 55	Two Sample t-Test		✓ (a)		✓

Note: N/A = Not applicable, (a) = Small relaxation in p-value (significance level) would have led to rejection of the null hypothesis.

The results of the analysis conducted using the Kruskal-Wallis and t-Test contributed to the elimination or reconfiguration of the following parameters: push versus pull, evolutionary versus revolutionary; single project versus portfolio; budget constraints/disruptions, Advancement Degree of Difficulty (AD²), and hardware versus software. The parameter for hardware was eliminated and software was expanded to include additional parameters based on information to be acquired by submission of Software Management Plans in accordance with NPR 7150.2A.

A qualitative analysis was performed to establish the preferred parameters to be used in Technology Estimating. The qualitative analysis is included in Appendix A.

Based on the statistical analysis conducted, Table 1 and the qualitative analysis, Appendix A, the cost estimating parameters recommended for use in estimating the cost and schedule of technology R&D with low maturity, i.e. TRL less than 6, are included in Table 2. Each parameter was classified as a qualitative or quantitative data type. Seven of the 15 Technology Estimating parameters are included in *TechPort*.

Table 2
Technology Estimating Parameters

Category	Parameter	Data Type		Included in TechPort
		Qualitative	Quantitative	
Project Characterization	Technology Area	✓		✓
	System Hierarchy	✓		
	Defining system characteristics	✓	✓	
	Computer Software			
	Project Type	✓		
	Software Class*	✓		
	Primary Language	✓		
	Number of Requirements		✓	
Projects Results	Software Size		✓	
	Key Performance Parameter(s)		✓	✓
	Level of Effort		✓	
	Actual Cost		✓	✓
Development Metrics	Schedule (Start and End Date)		✓	✓
	TRL	✓		✓
Project Execution	RD ³	✓		
	Funding source(s)	✓		✓
	Performing Organizations	✓		✓
	Team Experience	✓		
Programmatic Factors	Facilities and Infrastructure		✓	
	Unplanned Event(s)	✓	✓	

Note: TRL = Technology Readiness Level; RD³ = Research and Development Degree of Difficulty;
* = Class A, B, C, D, or E in accordance with NPR 7150.2A

Cost Estimating Relationships

The TCASE cost and schedule tool is currently an analogy based cost and schedule estimating tool. Its future development includes the application development and use of parametric analysis once sufficient project data is available. The continued increase of data will allow the analysis to be conducted for subsequent establishment of Cost Estimating Relationships (CERs). Obtaining an adequate number of data in each of the Technology Areas and sub-TAs present has presented a challenge for derivation of CERs that span the four Technology Areas that were initially investigated, i.e. TA03 Robotics, TA04 Power, TA08 Instrumentation, and TA12 Materials. It was determined that CER development for the balance of the remaining Technology Areas will be accomplished after cost and schedule data can be fully acquired from sources such as *TechPort*.

The validity of a CER will usually be judged by its regression statistics, which measure the accuracy of the fit of the CER to the sample data points used in developing the CER. The most commonly used regression statistic is the coefficient of determination (R^2), sometimes described as “goodness-of-fit”. A CER that perfectly predicts each sample point in the database would have an R^2 of 1.0. For CERs,

an R^2 value of 0.9 or better is considered desirable, although in practice, CERs with R^2 values of 0.8 or better may be accepted for use in a cost estimate.⁽⁴⁾

The format of the CERs to be developed for Technology Estimating should follow The Project Cost Estimating Capability (PCEC). In 2013, NASA began investigating the development of changes to the existing cost estimating data platforms. The Project Cost Estimating Capability (PCEC) was identified as a new framework that will replace NASA Air Force Cost Model (NAFCOM) as the standard NASA capability for estimating the cost of new spaceflight hardware systems during concept exploration and refinement. When the development is complete, the PCEC will be an Excel™ based architecture that combines a user interface running Visual Basic Algorithm (VBA) with Work Breakdown Structure (WBS) and CER libraries.

Technology Estimating Process

The Technology estimating process includes the acquisition of data for use the Technology Estimating Cost and Schedule Estimating tool. Multiple sources of data have been investigated and the most robust source of data determined viable for low maturity technologies, i.e. TRL less than 6.

TechPort is NASA's premier information portal for research and development technology. It has been identified as a significant data source for Technology Estimating. Of the 15 technology estimating parameters identified for support of Technology Estimating (Table 3), seven parameters are already included in *TechPort*. Eight additional parameters have been identified that support the Technology Estimating process should be included in *TechPort*. To facilitate the addition of eight additional Technology Estimating parameters in future changes to *TechPort*, Table 3 indicates a suggested order sequence for their inclusion. A sequencing of these additional parameters into *TechPort* would also help to integrate changes systematically, adjust users to these new parameters methodically, and help reduce or minimize potential errors in their application.

The priority for order of sequence was a ranking from "1" the highest priority to be implemented first, to "3" the lowest priority to be implemented last. The rank and priority was based on:

- The metric associated with the parameter,
- The parameters' perceived ease of application as observed during the Technology Estimating research project,
- Experience for the parameters' use and application by Technology Managers as observed during the research, and
- The parameters' level of definition.

Table 3
Technology Estimating Parameters to Be Added in *TechPort*

Category	Parameter	Data Type		Priority and Sequence for Inclusion in TechPort
		Qualitative	Quantitative	
Projects Results	Level of Effort		✓	1
Development Metrics	RD ³	✓		1
Project Execution	Team Experience	✓		1
Project Characterization	System Hierarchy	✓		1
Project Characterization	Defining system characteristics	✓	✓	2
Project Characterization	Computer Software			
	Project Type	✓		2
	Software Class*	✓		2
	Primary Language	✓		2
	Number of Requirements		✓	2
	Software Size		✓	2
Project Execution	Facilities and Infrastructure		✓	3
Programmatic Factors	Unplanned Event(s)	✓	✓	3

Note: TRL = Technology Readiness Level; RD³ = Research and Development Degree of Difficulty. * = Class A, B, C, D, or E in accordance with NPR 7150.2A

The TCASE tool should include projects from *TechPort* for use in Technology Estimating. Once cost and schedule data are obtained from *TechPort*, for all of the NASA Technology Roadmap areas 1 through 14, and a level of confidence is obtained for importing data and Technology Estimating, then additional Technology Estimating parameters, as identified in Table 3 should be incorporated sequentially according to its indicated priority.

Administration of Technology Estimating Process

The process for technology estimating includes the use of data for completed research and development projects with low maturity. A chart, Figure 2, indicating proposed administration activities was prepared to reveal the path of project data from initiation of the project by the Technology Owner to the project documentation data sources such as *TechPort*, Cost Analysis Data Requirements (CADRE) by NPR 7120.5E, and Software Management Plans submitted in accordance with NPR 7150.2A. Other project data have been migrated to TCASE such as those data sources identified in Table 4.

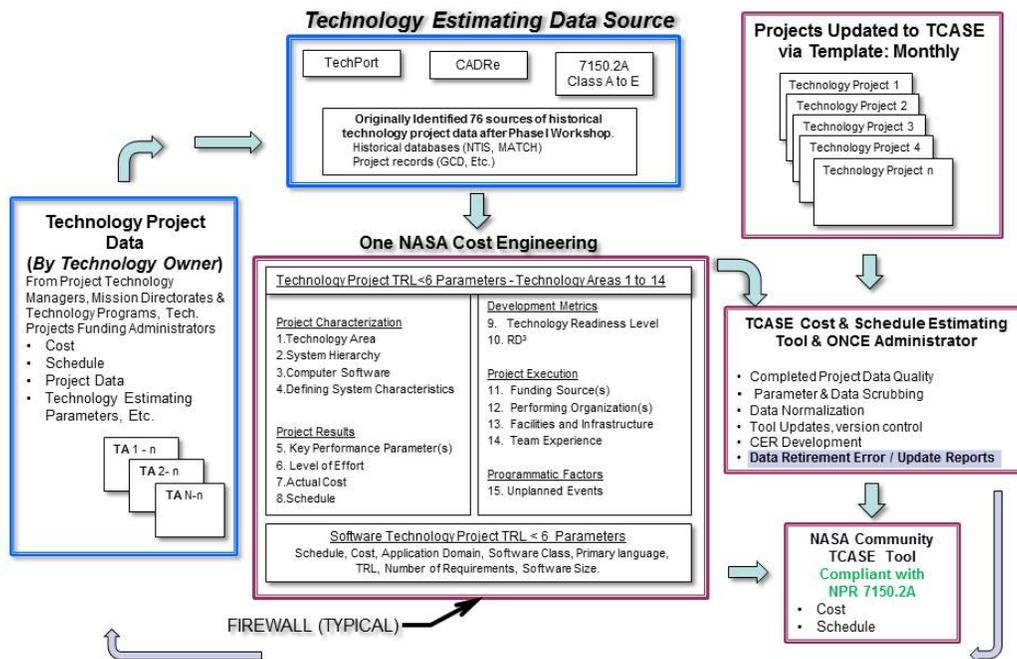
Table 4
Data Sources Used in this Research ⁽⁵⁾

Short Name	Description	Year	Entries
ETDP	NASA Exploration Technology Development Program	2012	42
ESTO	NASA Earth Science Technology Office	2012	138
SBIR	Current NASA SBIR Technologies	2012	51
GCD	Game Changing Development Program Office Technology Projects	2012	35
ESMD	NASA Exploration Systems Mission Directorate ESAS Technologies	2005	304
Tech Tool Box	ATLAS (Advanced Technology Lifecycle Analysis System)	2002	6
Ext Tech Data	Tauri Group research into External Government Technologies (EGT within the MATCH relational database)	2012	28
Cx ETDP	Constellation Exploration Technology Development Program	2007	19
NTID	NASA Tech Inventory Database	2004	991
Hist SBIR STTR	Historical SBIR and STTR data	2012	1191
RLV Tech DB	NASA RLV Technology Database	1993	64
HEOMD TechDev Team	Estimates of HEOMD needed technology developments	2012	78
ETDP from MATCH	Mapping Applicable Technology To Exploration Challenges	2007	21
External from MATCH	Mapping Applicable Technology To Exploration Challenges	2007	192
JSS TBCC	NASA/Air Force Joint Systems Study TBCC Technologies	2010	18

Individual project data from the data sources are then migrated to One NASA Cost Engineering (ONCE) for use in the TCASE tool. The data for TCASE can be reviewed by an Administrator who will review data quality, assess parameters and perform any needed data scrubbing; tool updates, distribution and version control; and CER development. Any data that requires retirement due to age or applicability will be evaluated by the TCASE Administrator and notify the Technology Owner of any errors, omissions or issues as may be determined helpful.



Technology Estimating



TCASE Cost & Schedule Estimating Tool & ONCE Administrator

- Completed Project Data Quality
- Parameter & Data Scrubbing
- Data Normalization
- Tool Updates, version control
- CER Development
- Data Retirement Error / Update Reports

NASA Community TCASE Tool Compliant with NPR 7150.2A

- Cost
- Schedule

Figure 2. Technology Estimating process

Data Migration from TechPort to the TCASE Tool

TechPort is NASA’s repository of information on each individual project within NASA R&D programs. The *TechPort* R&D projects are searched by several parameters including seven of those identified for Technology Estimating. Representative parameters included are the project name, start and end date, NASA technology roadmap area, and key performance parameter, etc. After the *TechPort* user completes a selection process, the multiple attributes for each of the selected projects are then downloaded to an EXCEL™ spreadsheet.

Currently, due to gaps observed in the project records for a project in *TechPort*, the completeness of Technology Estimating parameters may not always be fulfilled or included for the respective project data file and therefore a parameter field may be blank or omitted. A February 2014 survey of project records for “completed” projects indicated that a critical parameter such as “cost” data may not have been imported to *TechPort* by the Technology Owner. The lack of cost data in *TechPort* impedes the Technology Estimating capability. Currently, the TCASE (version 5.0) tool was designed to be configured to accept a download of the projects EXCEL™ attribute file directly from *TechPort*.

Future anticipated refinement of ONCE will be expected to be configured to allow the project data exported or downloaded directly from *TechPort* to ONCE. As the data will be “mirrored” from *TechPort* to ONCE, no modifications to *TechPort* will be necessary with respect to Technology Estimating. As ONCE will be the data repository for Technology Estimating, the project data will be normalized and evaluated for use in Technology Estimating. If errors are found in the data, which are located in ONCE, questions arise, or the data needs to be retired, then the TCASE Administrator will make the changes in ONCE or notify the respective Technology Owner directly as may be required.

Data Migration from CADRe to the TCASE Tool

CADRe is NASA's primary technology data file for projects meeting requirements of NPR 7120.5E. The CADRe is prepared by the CAD using existing project data prepared during the life-cycle review process. By capturing key information, the CADRe tracks and explains changes that occurred from one milestone to the next, and it helps the project manager record in an Agency document all the events that occurred during the project both internal and external. The CADRe is a project owned document and is signed by the project manager; therefore, it does not include any independent assessments or evaluations, or opinions about the project. It simply records the known configuration at the specific milestone. The CAD provides the necessary funding and contractor support to prepare the document on behalf of the project using existing project documentation prepared during the milestone review process. Composed of three parts, the CADRe captures detailed programmatic, technical, and cost data in a standardized format. The document is prepared six times during the life cycle of a project at major milestones (SRR, PDR, CDR, SIR, Launch, End of Mission). Currently, CADRe and the data being included in the database are potentially migrating to the PCEC, and ONCE. Future refinement of ONCE should allow the data for technologies (projects) with TRL less than 6 to be included in TCASE.

Data Migration from NPR 7150.2A Software Management Plans to the TCASE Tool

Observations made during the research indicated that a significant portion of the technology effort might be attributed to the development of computer software. Software applications may be required for support other Technologies, or required as an integral part of the technology R&D. Segregating this software effort could be accomplished via use of the Software Management Plans (SMPs) required by NPR 7150.2A. The SMPs contain pertinent data about the software and includes the parameters that drive the cost and schedule. As identified in Table 3, the Technology Estimating parameters identified for computer software include project type, software class, primary language, number of requirements, and software size.

Data Tracking

Technology R&D projects may be initiated within any number of potentially 42 different NASA R&D programs. Technology owners may initiate a project in one NASA Technology Roadmap area and the project may take on follow on work that could progress into later phases of work, "morph" into other technology areas, or there may be successive parent-daughter technology projects. ***Tracking the initial R&D technology projects and its follow-on work is paramount to obtaining the total cost and schedule of a particular technology as would be accomplished in Technology Estimating.***

Based on the findings from this research, tracking a technology projects cost, schedule, and other pertinent project data through the succession of phases has been identified to be complicated by a number of items. These include:

- The Principal Investigator left the project where there is no information related to their succession,
- The R&D project work did not result in a formal technical paper,
- Contract or research grant identifying numbers were not identified in the research technical paper,
- The project administration of the research did capture the R&D project administration information in a centralized NASA location similar to *TechPort*,
- The project records were archived and are difficult to retrieve,
- Funding made by two separate NASA organizations on the same research project could not be connected without identification of the original contract number, or WBS numbers were unavailable,
- Project funding was postponed,

- The research scope changed, or was transferred to another program, or
- Information in the acknowledgment section of the technical paper did not indicate sufficient information to connect with previous or succession work.

Tracking technology is best accomplished from the beginning of the R&D work where the Technology Owner's researcher is notified of the requirement to complete and submit all the applicable information to TechPort at the conclusion of the work. This new requirement would be identified in two primary documents. The first is NASA's Guidebook for Proposers Responding to a NASA Research Announcement (NRA) or Cooperative Agreement Notice (CAN), January 2013 Edition, and the second is NPR 5800.1 Grant and Cooperative Agreement Handbook, Section A, Part 1260, Grants and Cooperative Agreements, § 1260.77, Closeout procedures, located at https://prod.nais.nasa.gov/pub/pub_library/grcover.htm.

During this research, it was identified that some technical papers reviewed did not always reveal a clear line of technology succession even though multiple papers were identified by author and successive dates. A possible solution to help reveal technology and their successive technologies is a new requirement to be incorporated in NASA's Science and Technical Information (STI) paper submission process. The NASA documents to be modified to help in the tracking effort would include NPD 2200.1B, Subject: Management of NASA Scientific and Technical Information, Effective Date: November 19, 2009, Expiration Date: November 19, 2014; NPR 2200.2C, Requirements for Documentation, Approval, and Dissemination of NASA Scientific and Technical Information, Effective Date: April 19, 2011, Expiration Date: April 19, 2016. ***Additional research should be conducted to determine the best method for tracking technologies and identified in the "Acknowledgement" section of the technical paper.***

Tracking technology R&D by the use of Work Breakdown Structure (WBS) as a means for classification of technology was not considered in this research. It was found that the majority of NASA's individual R&D low maturity projects with TRL less than 6 typically did not appear to have a WBS. Portfolios of low maturity R&D technology projects were thought to follow the portfolio requirements of NPR 7120.8, Chapter 5 by use of a Portfolio Project Plan as required by NPR 7120.8, NASA Research and Technology Program and Project Management Requirements (w/change 3 dated 04/18/13) Section 5.2.5 Project Implementation, 5.2.5.1. In the Implementation phase, the R&T Portfolio project lead executes the R&T Portfolio Project Plan, which usually consists of one or more portfolio cycles (see section 5.2.5.7).

These Portfolio Project Plans were not reviewed in this Technology Estimating research as the effort was outside the research scope. ***Further research should be conducted to determine the extent of tracking requirements as could be identified in the administration of NASA's low maturity R&D projects by NPR 7120.8.*** This tracking of individual projects, as managed in the Portfolio Project Plan could prove useful and whether WBS for individual projects over portfolios would prove valuable to Technology Estimating.

For reference, the WBS Template worksheets in the PCEC Library v0 have been formatted with a blue tab colors and each WBS worksheet contains a WBS. The following three WBS types are included in the PCEC: 1) NASA NPR 7120.5E WBS which is the NASA WBS. At this time the NAFCOM/PCEC CERs do not estimate to the WBS structure and is included in the PCEC for reference; 2) the CAD Requirements (CADRe) WBS which is used to collect data for NASA CADRe documents and is included in the PCEC for reference.; and 3) NFC12 WBS where it was derived from NAFCOM. The current PCEC/NAFCOM CERs align to these WBSs. Each template represents one of several major categories of systems produced by NASA.

Conclusion

Technology Estimating and the TCASE tool will provide a significant capability to Technology Managers and Technology Owners. The use of TCASE as an analogy based estimating tool has been demonstrated and the tool is continuing to be improved. Once additional project data has been included from sources such as NASA's *TechPort*, the value of the tool as an aid in estimating the cost and schedule of NASA R&D technology will increase greatly and its popularity for use in the cost community should expand.

A critical gap in the Technology Estimating process was identified. The significant gap includes tracking initial and successive R&D technology projects. Closing this gap for tracking an initial project and a project's follow-on work was determined to be paramount for obtaining the total cost and schedule of a particular technology. It was found during this work that additional research should be conducted in three primary areas to help support R&D technology project tracking, thus directly supporting the Technology Estimating process:

- The first includes study to determine the best method for tracking technologies in technical papers. For example, these may include new requirements for specific notations to be identified in the "Acknowledgement" section of a technical paper. Further, where there is noted to be a succession of papers under the same contract, an annotation could be strategically identified. The implementation of these tracking requirements could be applied in NPD 2200.1B and NPR 2200.2C.
- The second area of additional study would be to determine the best methodology for tracking technology as it pertains to including project data in *TechPort*. It is suggested that tracking technology may best be accomplished from the beginning of the R&D work, where the Technology Owner's researcher is notified of the requirement to complete and submit all the applicable information to *TechPort* at the conclusion of the work, i.e. during closeout. Consideration of the appropriate changes to NPR 5800.1 could improve tracking of technology projects and support Technology estimating as Technology Owners could be required at the beginning of their work to complete data input to *TechPort* at the conclusion of the project.
- The third area of additional study to be conducted would be to determine what technology tracking requirements that could be applied to the Portfolio Project Plan as required by NPR 7120.8, and if the NASA WBS can be successfully applied to low maturity technology projects.

The technology estimating parameters used in the estimating process were analyzed and based on both a statistical and a qualitative analysis. A total of 15 final Technology Estimating parameters have been recommended. Seven of these 15 parameters were identified to be already included in *TechPort*. A sequence and priority for the inclusion of the eight additional parameters into *TechPort* was identified. The eight additional parameters include System Hierarchy, Defining system characteristics, Computer Software, Level of Effort Research and Development Degree of Difficulty, Team Experience, Facilities and Infrastructure, and Unplanned Event(s). The addition of these parameters into *TechPort* should progress as a phased sequence where the benefit for including these eight additional parameters into *TechPort* will significantly outweigh the cost for their implementation.

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Appendix A

Qualitative Analysis of Technology Estimating Parameters

The following is a list of the parameters recommended for use in Technology Estimating process. The attribute of the parameter was identified as either qualitative or quantifiable and the use of both type would help describe the technology. Further, a rank for ease of administration of the parameter was identified. This ease of administration was based on observations made by the Research Team throughout the project. Generally, the guiding tenets for development of Technology Estimating parameters include that an item is a schedule/cost driver if a parameter tends to increase or decrease schedule/cost or is highly correlated with schedule/cost.

Following each parameter is a narrative discussion. The discussion was provided to indicate any observations made during the research and help address the parameters suitability for use.

1. Parameter related to Project Characterization: Technology Area (TA)

- a. Metric Attribute: Qualitative
- b. Rank Ease of Administration: High
- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. Technology areas in secondary and tertiary breakdown were sometimes difficult to apply by Technology Managers in all cases due to level of familiarity in application of the parameter. There is substantial documentation used to define these TAs and overtime, the use of the parameter will become easier for application and use.
- f. This parameter only applied to recent projects as the 14 TA Roadmap was promulgated within the last two years.
- g. Technology Area (TA) significantly helps to refine the Technology, however branching TAs can or may be questioned with regard to the accuracy of their application versus definition.
- h. Different individual TAs are naturally expected to have generally different schedule and costs.
- i. This parameter is included in TechPort.

2. Parameter related to Project Characterization: System Hierarchy

- a. Metric Attribute: Qualitative
- b. Rank Ease of Administration: High
- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. This parameter was relatively easy to be applied by Technology Managers. The distinction between the various level of system hierarchy can be close, depending on the system.
EXAMPLE: If a satellite (mission i.e. “platform” or “system of systems”) had multiple sub-systems comprising the total science package, it could not readily be determined that a technology was itself a complete system or was it to be included in the larger science system or platform.
- f. Will benefit from a standard reference and definition to help clarify appropriate level in the hierarchy.

3. Parameter related to Project Characterization: Defining System Characteristics

- a. Metric Attribute: Qualitative and Quantifiable
- b. Rank Ease of Administration: High

- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. Provides the detailed characterization of TAs.
 - f. Helps to characterize between technologies in same TA and for branching technologies from a single TA.
 - g. This parameter includes metrics such as mass, volume, power, etc.
 - h. With future data, the characterization could reveal that for some TAs i.e. 08 Instrumentation, that they follow Moore’s Law where “number of transistors on integrated circuits doubles approximately every two years” or possess smaller volumes, and less mass due to increased computing capability.
4. Parameter related to Project Characterization: Software
- a. Metric Attribute: Qualitative and Quantifiable
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: Yes
 - d. Cost Driver: Yes

DISCUSSION

- e. Recommended that “Hardware” be dropped from original parameter (hardware versus software) as it did not provide significant correlation to amount or extent of software in all technologies.
 - f. Suggested typical software cost drivers include: Project type, Software class, (i.e. A, B, C, D or E), Primary language, Number of requirements, and software size.
 - g. Software development and its cost and schedule increases can be expected to be significant in the range of TRL 5 to 6.
 - h. Technology papers for technologies with TRL < 6 indicate sometimes one or two persons exclusively dedicated to software when required. Extent of software used in R&D technologies was observed to be major influence to the cost and success of the technology.
 - i. Data for software cost drivers are being collected as part of NPR 7150.2A Software Management Plan and can be used in Technology Estimating.
5. Parameter related to Project Characterization: Key Performance Parameter (KPP)
- a. Metric Attribute: Qualitative and Quantifiable
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: Yes
 - d. Cost Driver: Yes

DISCUSSION

- e. This parameter normally includes any and all technology project objectives.
- f. The KPPs provide significant and relevant data about the project and its intended functional objectives.
- g. This parameter provides the description in sufficient detail to compare it against similar technology projects.
- h. This parameter also provides technical details such that branching applications may be understood.
- i. When adequate data is provided, technologies with similar objectives may be compared by their respective schedule and cost.
- j. The parameter is included in TechPort.

6. Parameter related to Project Results: Level of Effort
 - a. Metric Attribute: Quantifiable
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: No
 - d. Cost Driver: Yes

DISCUSSION

- e. This parameter includes manpower estimate for NASA civil servant but does not capture the cost of universities, faculty, students, adjunct research investigators, etc.
- f. Currently, at the resolution of the project data obtained to date, the analysis indicates that the data cannot support that Level of Effort drives the schedule.
- g. Includes the capture the contracting costs in WYEs.

7. Parameter related to Project Results: Cost
 - a. Metric Attribute: Quantifiable
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: Yes
 - d. Cost Driver: Yes

DISCUSSION

- e. This parameter includes the total cost (actual).
- f. It is suggested that the cost per year be obtained and identified with the respective year.
- g. The cost that should be identified as the cost in the management information system.
- h. The parameter is included in TechPort.

8. Parameter related to Project Results: Schedule
 - a. Metric Attribute: Quantifiable
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: Yes
 - d. Cost Driver: Yes

DISCUSSION

- e. This parameter includes the total duration (actual).
- f. It is suggested that the total duration be identified by beginning and end dates.
- g. The duration that should be identified is the time in the management information system.
- h. The parameter is included in TechPort.

9. Parameter related to Development Metrics: Technology Readiness Level
 - a. Metric Attribute: Qualitative
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: Yes
 - d. Cost Driver: Yes

DISCUSSION

- e. This parameter includes the Technology Readiness Level as it is submitted by the Technology Manager, PI, PM or Technical Paper.
- f. It is suggested that the TRL for a technology be assessed by an unbiased referee.
- g. It has been reported that the TRL may undergo changes in definition in the future.
- h. The parameter is included in TechPort.

10. Parameter related to Development Metrics: Research and Development Degree of Difficulty (R&D³)
- a. Metric Attribute: Qualitative
 - b. Rank Ease of Administration: High
 - c. Schedule Driver: Yes
 - d. Cost Driver: Yes

DISCUSSION

- e. This parameter includes five categories and can be difficult to administer.
- f. The use of this parameter in this research was impeded somewhat by subjectivity for its application.
- g. The statistical analysis reveal that the parameter may be a cost and schedule driver.

11. Parameter related to Project Execution: Funding Sources

- a. Metric Attribute: Qualitative
- b. Rank Ease of Administration: High
- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. Comments from Technology Managers revealed that certain funding sources such IRAD programs do not provide enough time in the funding program to fully accomplish the technology project efforts.
- f. NASA undergoes a mix of funding programs, i.e. ETDP to GCPDO, etc. and the funding sources help to identify tracking of the technology and for branching of the technology.
- g. A gap exists for Tracking technologies from lower TRL to higher TRL, or from incubation to mission level. There is no way to identify if the work has been ceased due to funding, lack of capability or other reasons. The parameter was understood to be an imperative as it pertains to understanding technology infusion.
- h. The parameter is included in TechPort.

12. Parameter related to Project Execution: Performing Organizations

- a. Metric Attribute: Qualitative
- b. Rank Ease of Administration: High
- c. Schedule Driver: No
- d. Cost Driver: No

DISCUSSION

- e. Identification of organizations involved helps to identify tracking of the technology and for branching of the technology.
- f. The identification of organizations and points of contact is an imperative for tracking technology.
- g. There was a perception that the parameter could be a schedule or driver if a certain organization is identified with the Technology.
- h. The parameter is included in TechPort.

13. Parameter related to Project Execution: Team Experience

- a. Metric Attribute: Quantifiable
- b. Rank Ease of Administration: High
- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. Identification of the team structure goes directly to the schedule and cost driver of a technology.
- f. The team structure was not well documented in any of the data sources.
- g. The team makeup would be noted in project administration records and should be identified. Categories in this parameter include: Little or no experience conducting research, Experience conducting research but little or no experience with specific technology, Experience with research of this specific technology, Experience with this specific technology and innovative team.

14. Parameter related to Project Execution: Facilities and Infrastructure

- a. Metric Attribute: Quantifiable
- b. Rank Ease of Administration: High
- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. Identification of the facilities or infrastructure goes directly to the schedule and cost driver of a technology.
- f. The use of aircraft for testing was expected to be a large expenditure, however the cost was not normally documented.
- g. Some laboratories were noted in the literature to be specialized and there should have been a cost identified for these labs.
- h. Certain University test facilities by were noted in discussion with Technology Managers to severely impact the delivery date of a technology project. These types of changed conditions should be noted in project administration records and their impacts noted for use in Technology Estimating.

15. Parameter related to Programmatic Factors: Unplanned Events

- a. Metric Attribute: Quantifiable
- b. Rank Ease of Administration: High
- c. Schedule Driver: Yes
- d. Cost Driver: Yes

DISCUSSION

- e. This parameter includes budget constraints and disruptions including any and all significant events to the capture of any or all impacts to the project such as change orders, requirements change, or unforeseen conditions.
- f. This parameter should include any singular event(s) that that contribute to or impact the cost or schedule of the project.
- g. This parameter also includes any budget constraints and disruptions during the term of the work.

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14. ABSTRACT As a leader in space technology research and development, NASA is continuing in the development of the Technology Estimating process, initiated in 2012, for estimating the cost and schedule of low maturity technology research and development, where the Technology Readiness Level is less than TRL 6. NASA's Technology Roadmap areas consist of 14 technology areas. The focus of this continuing Technology Estimating effort included four Technology Areas (TA): TA3 Space Power and Energy Storage, TA4 Robotics, TA8 Instruments, and TA12 Materials, to confine the research to the most abundant data pool. This research report continues the development of technology estimating efforts completed during 2013-2014, and addresses the refinement of parameters selected and recommended for use in the estimating process, where the parameters developed are applicable to Cost Estimating Relationships (CERs) used in the parametric cost estimating analysis. This research addresses the architecture for administration of the Technology Cost and Scheduling Estimating tool, the parameters suggested for computer software adjunct to any technology area, and the identification of gaps in the Technology Estimating process.					
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