A Method for Total Baseline Integration

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Abstract. Advancements in technology continue to enable our society to design and implement more complex systems to achieve more ambitious missions. As systems become more and more complex, it is incumbent on the systems engineering practitioners to develop new and innovative methods to ensure our systems are cable of fulfilling their intended missions in an efficient and effective manner. This paper describes one such method known as Total Baseline Integration ™ (TBI), developed through corporate investment at Booz Allen Hamilton. As part of an internal study on why programs to develop large complex systems often fail to meet cost, schedule, and/or performance objectives, one recurring theme became evident. As systems grow in complexity, it becomes more and more difficult to tightly integrate the programmatic baselines for performance, cost, schedule, and risk. We have a tendency to further complicate this situation by setting up our organizations such that these functions do not come together organizationally until they reach the Program Manager level. This is primarily due to the fact that control and management of these baselines requires different skill sets. There is a natural tendency to separate the staff performing these duties and often times they are even acquired through separate procurements of support staff. This paper will discuss a methodology we have developed to physically link and analyze these baselines. The goal and ultimate result of the methodology is to provide a more holistic assessment of the impact across program baselines for any proposed changes or alternatives.

Introduction

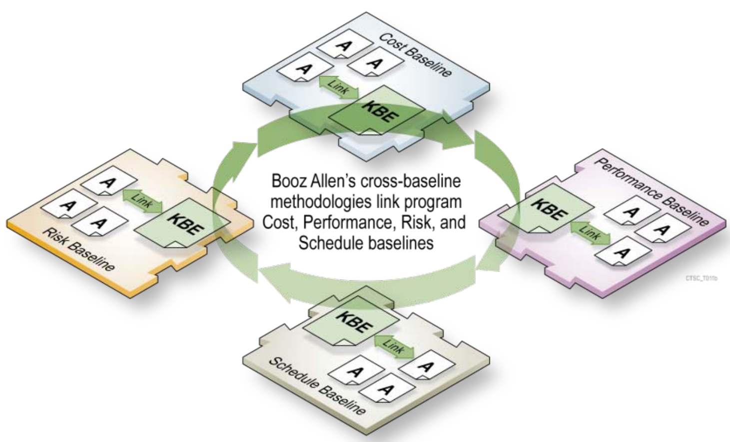
Today's mission capability needs have resulted in increasingly complex program environments. Today's programs are larger, last longer, involve diverse stakeholders, must achieve aggressive technical and performance goals, and comprise system-of-systems environments with intricate interdependencies. Changing user needs, evolving external influences, challenging programmatic constraints, and complex technical capabilities mean that program management and technical leaders need timely information that reflects the impacts of changes across all aspects of the program. Current systems engineering and business management processes may deliver excellent analysis, but they were not developed to provide integrated, actionable information across all aspects of today's complex programs. All too often, program performance, cost, schedule, and risk baselines are still created and managed separately using different approaches, making it difficult to quickly understand tradeoffs across these dimensions. Booz Allen Hamilton, a leading strategy and technology consulting firm, has invested significant resources over the past 3 years in a sustained effort to understand the root causes of program acquisition and development successes and failures. We identified the lack of consistent, coordinated development and management of performance, cost, schedule, and risk baselines as a critical barrier to program success. As a result, we developed the TBI methodology to integrate a program's performance, cost, schedule, and risk baselines. TBI enables program leadership to quickly evaluate the impacts of changes on any portion of the program across performance, cost, schedule, and risk baselines. We based TBI on existing proprietary methodologies that have been proven to provide tightly synchronized, efficiently managed, and well-integrated program execution.

TBI Overview

TBI seeks to ensure that program decisions are based on systematic, integrated impact assessments of perturbations to the cost, performance, schedule, and risk baselines. TBI achieves this objective by linking key artifacts and the knowledge base that reflect the program baseline (along with associated processes and tools) to enable the provision of alternatives that support program management decision-making. To support this methodology, we define the performance baseline to include the requirements, the architecture, and the operations artifacts that describe what the systems is intended to do, the design of the system, and how the system is intended to be operated.

TBI links the four program baselines (Cost, Performance, Schedule, Risk) through its products to:

- Understand the current state of a program throughout the program life cycle;
- Facilitate functional or design trades in a way that consistently captures cost, performance, schedule, and risk impacts;
- Allow objective communication of the true state of the program to internal and external stakeholders; and
- Identify and trace effects of perturbations to any given program baseline(s) on the other remaining baselines when program changes are imposed.



A high level overview of the TBI™ methodology is included in Figure 1. A key aspect to this approach is the development of a TBI index to use to link the baseline artifacts. When we first developed the TBI method, our initial instincts as systems engineers was use the Work Breakdown Structure (WBS) as the key construct for linking baseline artifacts. However, as we attempted to deploy the method we found that often the Program WBS is based on Program organization rather than the real work products. Therefore, we developed the concept of the TBI index to be a product based index derived from the system hierarchy diagram. If we are starting a new program with

TBI in mind, we ensure that the WBS is a product-based WBS, which in our opinion is the correct way to create a WBS. In those instances, the TBI index is the WBS. However, because we are often brought on to help Programs get back on track, we created the TBI index concept to support Programs with an organizational based WBS.

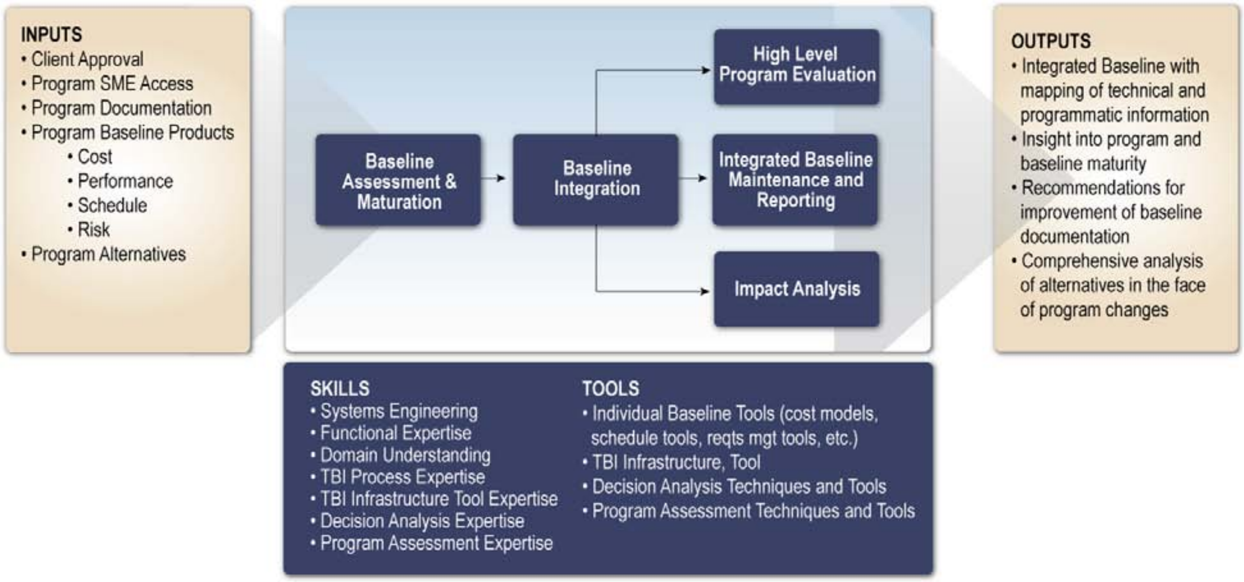


Figure 1: Overview of TBI Method

Approach

As shown in Figure 2, TBI High Level Flow, TBI is employed through a framework consisting of six Standard Operating Procedures (SOPs). These SOPs leverage proven system engineering and other processes to link and assess the four cost, performance, schedule, and risk baselines and then to maintain and analyze the resulting integrated structure.

SOPs 1 through 3 are executed when TBI is initially implemented into a program and seek to produce a normalized, integrated, and consistent set of baselines for the program. SOPs 4 - 5 are iteratively applied as needed throughout the life of the program to conduct analysis and maintain the integrated baselines. SOP 6 provides for tailored reporting, both initially and on an ongoing basis. Each SOP will be discussed in the following sections.

The TBI methodology requires data from the cost, performance, schedule and risk baselines in order to effectively employ TBI and maximize its benefit to the program/project. As the first step in the TBI methodology, the "Perform Data Discovery" SOP focuses on gathering and organizing the necessary input products and understanding program/project priorities and stakeholders. Not all programs/projects will have a set of baselines that are consistent in maturity or which map one-for-one to the expected set of products to support TBI. Therefore, this SOP may be tailored and will include a high level assessment of the program product alignment with TBI data requirements.

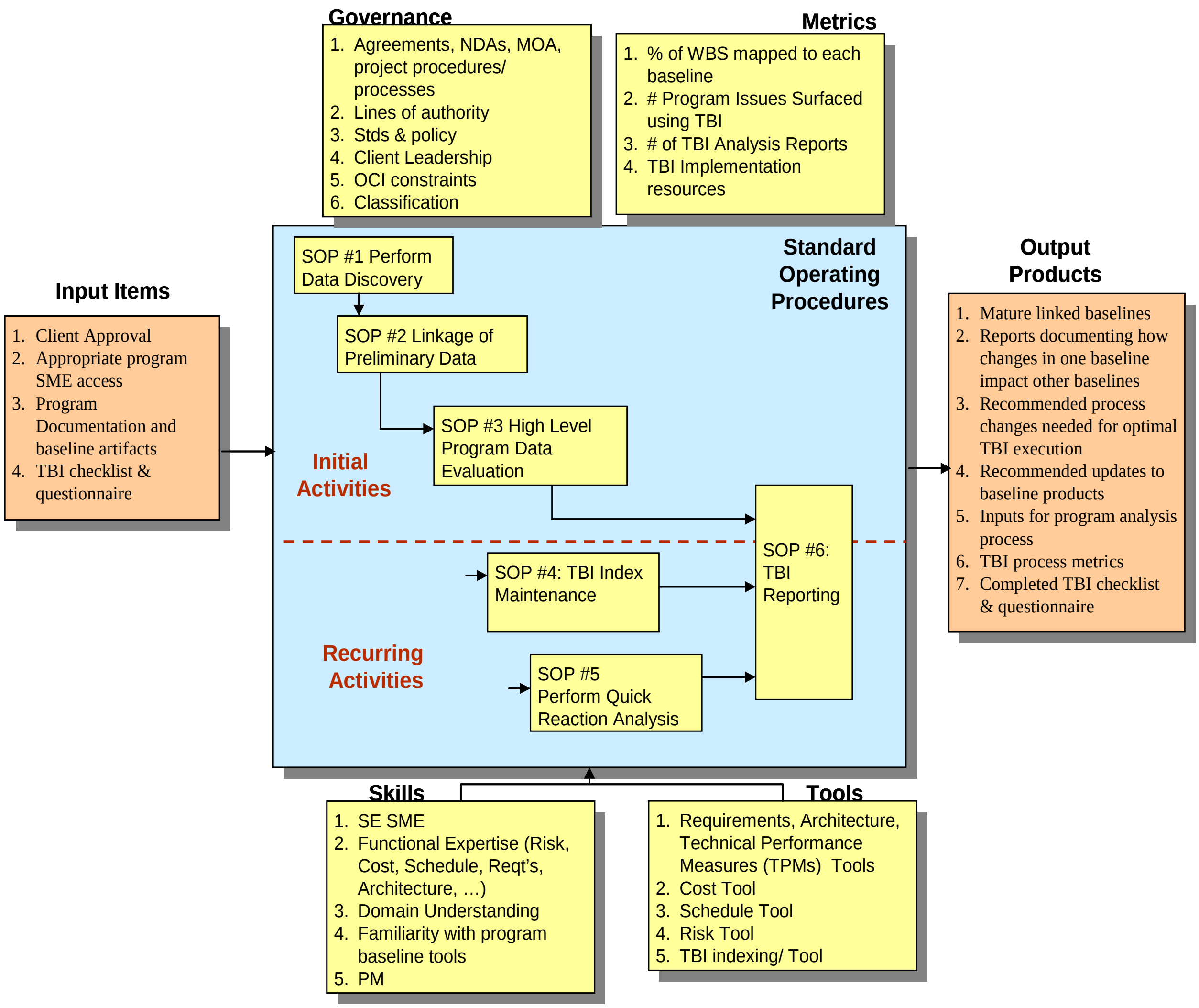


Figure 2. TBI High Level Flow

SOP #1 – Perform Data Discovery

The Data Discovery SOP ensures that the system engineers performing TBI tasks have a sufficient understanding of the program to guide the data discovery, assessment, and linkage activities. Therefore, this SOP begins with collection and review of all relevant information about the program, which is described here as orientation material. Next, the program baseline data is collected. A quick review and assessment of this baseline data will lead to a characterization of the maturity of the material. Finally there will be a set of interviews with program leadership to understand their perception of the program. Inputs for this SOP should include all appropriate program data and the main output will be an understanding of the documented baselines and overall maturity of the program. Any controlling agreements and policies will be considered as program governance. The basic metrics for this SOP will give insight into how much program data is available. This SOP will rely on 3 types of expertise: 1) system engineers and other TBI practitioners who will understand what types of data will be required to support program execution, 2) domain experts who understand the program's functions, stakeholders, leadership and users, and 3) functional experts who will apply their unique abilities (e.g., funding, program control, etc.). Figure 3 depicts the SOP # 1 Perform Data Discovery Flow.

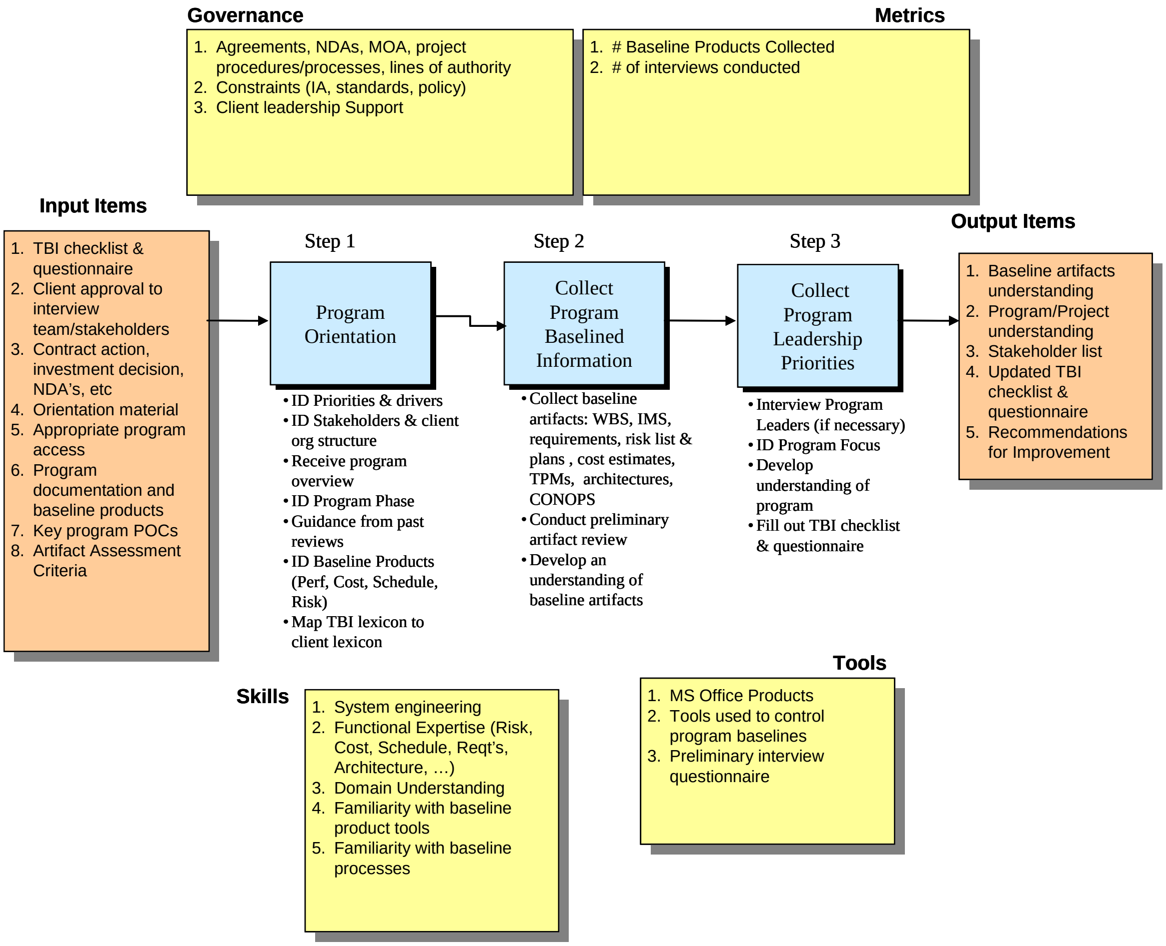


Figure 3. SOP#1 Perform Data Discovery Workflow

SOP#2 Linkage of Preliminary Data

SOP #2 provides for the linkage of the information collected in the earlier SOP #1 process, integrating cost, performance, schedule, and risk data into a cohesive, traceable TBI Index. The goal of this step is to produce linkages across the cost, performance, schedule, and risk areas, review the baseline artifacts collected in SOP # 1 to identify Key Baseline Elements (KBEs), observe baseline parameters and provide, as appropriate, a review of quality, consistency and depth of baseline products, with recommendations for improvement and added analysis.

The Linkage of Preliminary Data SOP is an activity that melds the available baseline artifacts into an integrated TBI Index baseline that provides the foundation for follow-on TBI activity. As such this SOP includes an analysis of the program's data and identifies critical gaps in the content. The Common Elements portion (Appendix I) of MIL-HDBK-881A (30 July 2005), *Work Breakdown Structures for Defense Materiel Items*, may be used as one departure point in considering adequacy of the WBS for TBI creation. Other similar non-DoD documents, such as NASA's product-based WBS for Space Flight Projects, mandated by NPR 7120.5D, may also be considered for use. Linkage of existing Performance requirements data hosted in tools like ReqPro, DOORS, or CRADLE, and architecture artifacts in Rational Rose, Popkins, or other tools, will support TBI Performance linkages. Figure 4 provides a view of SOP # 2.

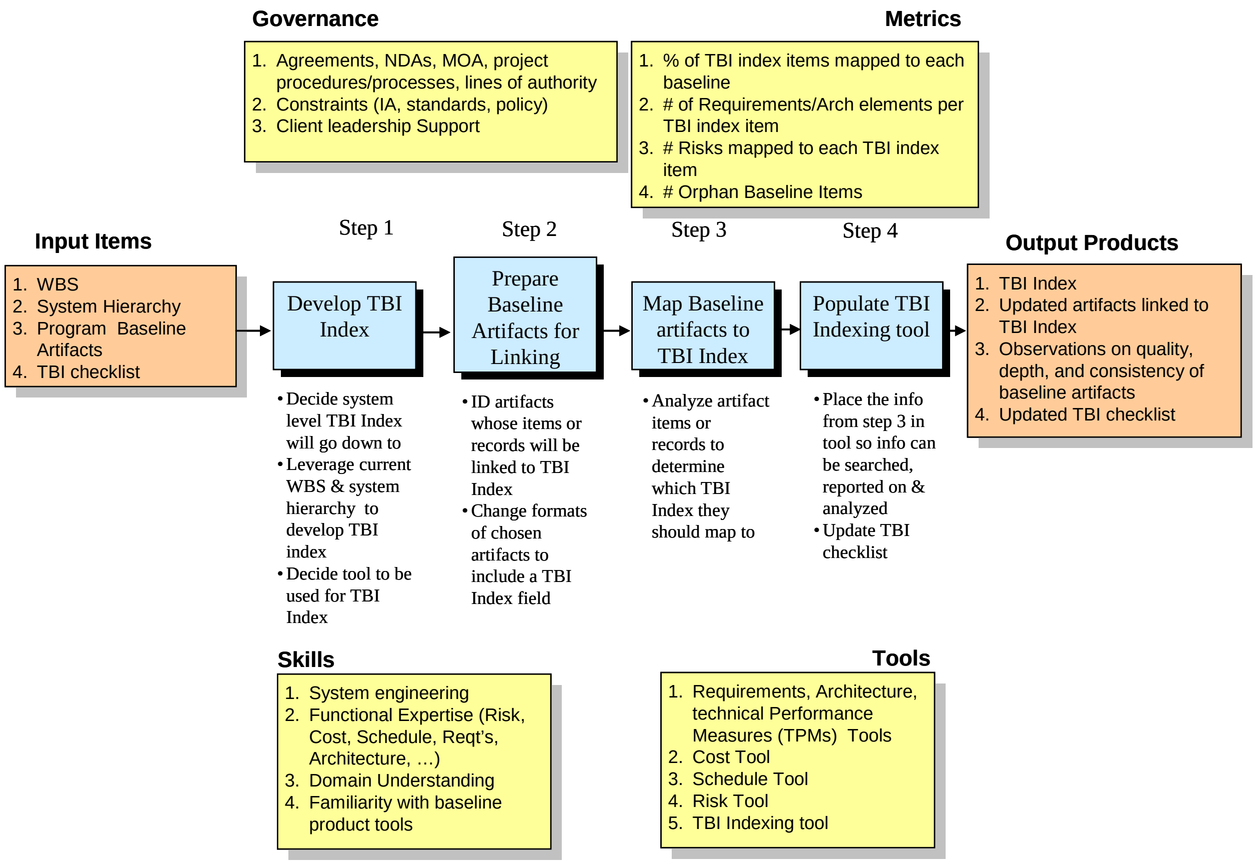


Figure 4. SOP # 2 – Linkage of Preliminary Data

SOP #3 - **High Level Program Data Evaluation**

The purpose of the High Level Data Evaluation SOP is to synthesize the overall program baseline data and be able to make some broad program observations. In some cases these observations have been apparent to the program leadership for some time but based on the TBI process there will now be traceable linkages to support specific insights into the impacts on the overall program. In some cases these observations are new and could not have been identified without linking the baselines.

A primary intent is to assess the "goodness" of the individual baselines, and it must be noted that program phase will affect quality. This understanding will provide views of clustering, gaps, overlaps and inconsistencies in the baseline data. These issues must be understood by program leadership when making decisions based on program baseline data. To execute this SOP an understanding of the purpose of the program, policies that govern accepted practices, program baseline data, and the best linkage between the four baselines must exist. The linked baselines will be the main input and a set of issues either with the data or for the program based on the data will be the main output. Metrics should be collected that can give the system engineer insight into the magnitude of any issues. SOP# 3 process steps are depicted in Figure 5 below.

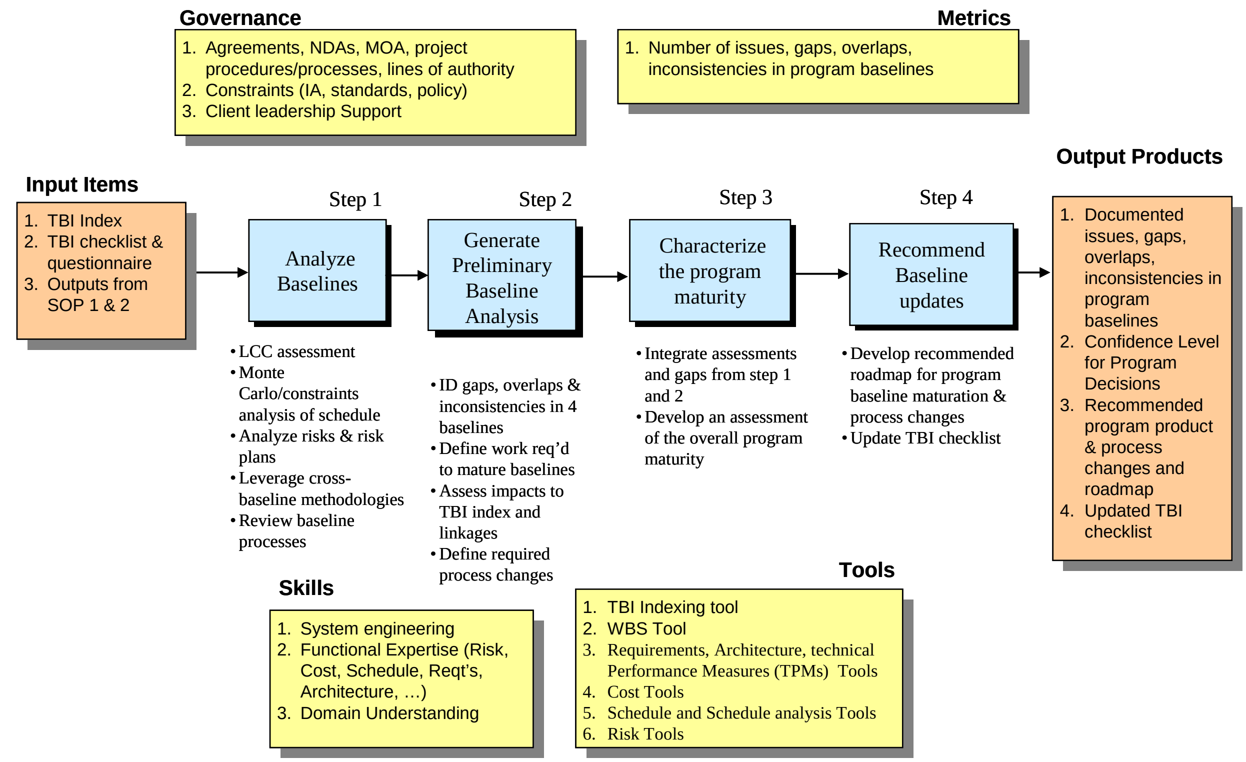


Figure 5. SOP # 3 High Level Program Data Evaluation

SOP #4 – TBI Index Maintenance

SOP #4 provides for the maintenance of the TBI Index, as it was established via SOP #2. As such, SOP # 4 closely aligns with the activities performed in SOP #2, except on an expected smaller scale. The intent of SOP #4 is the linkage of the information collected via follow-on maintenance actions to reintegrate cost, performance, schedule, , and risk data into an updated TBI Index, reflecting those changes.

The TBI Index Maintenance SOP melds updated baseline information into the existing integrated TBI Index, creating a new baseline for follow-on TBI activity. As such this SOP repeats, as applicable, the integration steps addressed in SOP #2, whereby cost, performance, schedule, and risk baselines are adjusted to reflect the impacts of each other and on the earlier baseline. This is the equivalent of “rewiring the backplane.” Metrics for this SOP will provide a view to the degree of change implemented in a given period. Figure 6 depicts SOP #4 TBI Index Maintenance.

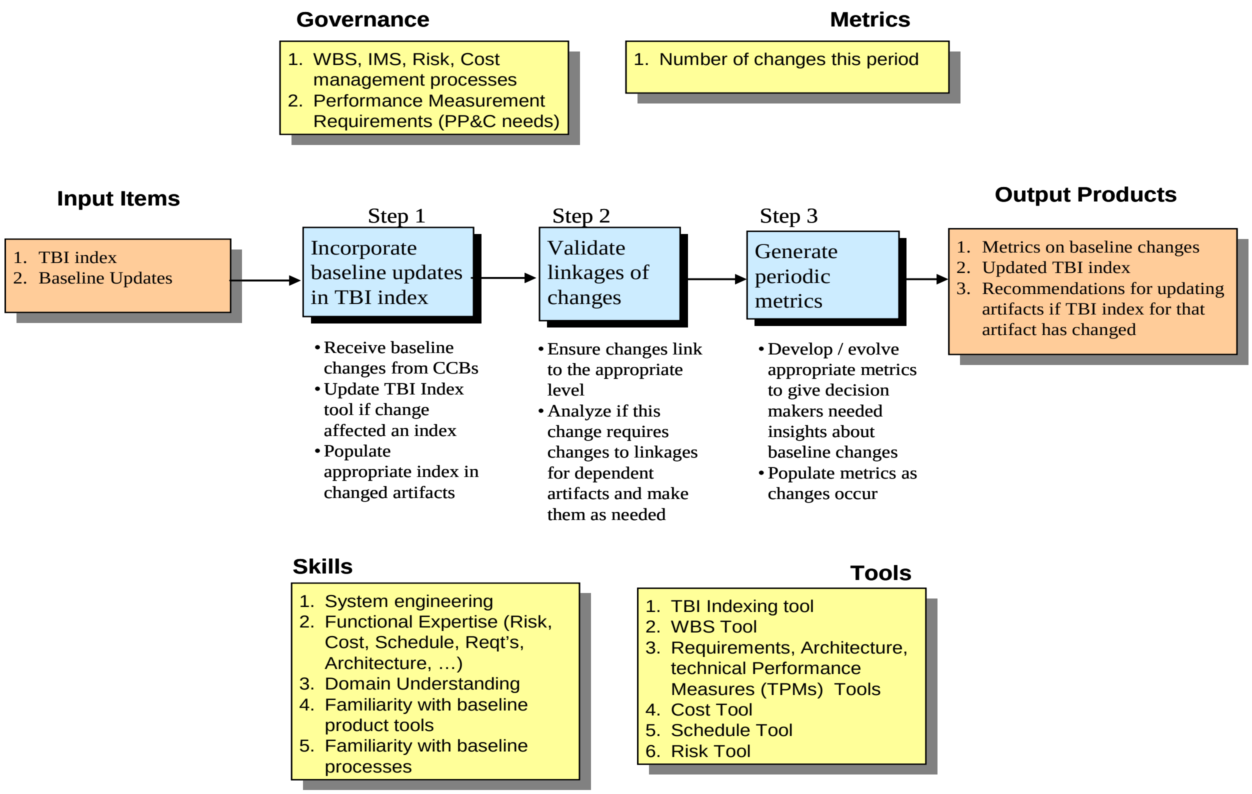


Figure 6. SOP # 4 – TBI Index Maintenance

SOP #5 – Perform Baseline Impact Analysis

The purpose of SOP#5 is to rapidly analyze impacts of changes to the previously developed linked baselines. This SOP analyzes an input problem statement (a ‘what if’), defines and assesses alternative solutions, determines solution impacts to the affected baselines and provides recommendations for Program changes.

This SOP leverages the preceding work by analyzing the linked baselines for impacts as a result of an actual or anticipated input stimulus, such as a budget increase, a schedule slip, the discovery of new risk, or a missed technology milestone. . In this SOP, a stimulus is first mapped to the immediately affected elements of the system hierarchy diagram. Based on the affected elements, the architecture is analyzed to identify baseline and propagated impacts to other parts of the system, and formulate or identify potential alternative solutions to address the input stimulus. If warranted, an alternative or adjusted TBI Index can be defined, including proposed changes to hardware, software, and supporting tasks. Each alternative may then be assessed from cost, performance, schedule, and risk, and linkage perspectives to determine if it is a feasible and integrated solution. This assessment enables an integrated decision analysis process. Results are peer reviewed and then presented to Program Management for action or further direction. While the process is depicted as linear, in implementation this process will often involve iterations as variations are identified within the solution space, requiring definition and assessment of additional alternative solutions. Figure 7 provides a view of the overall steps involved in executing SOP #5.

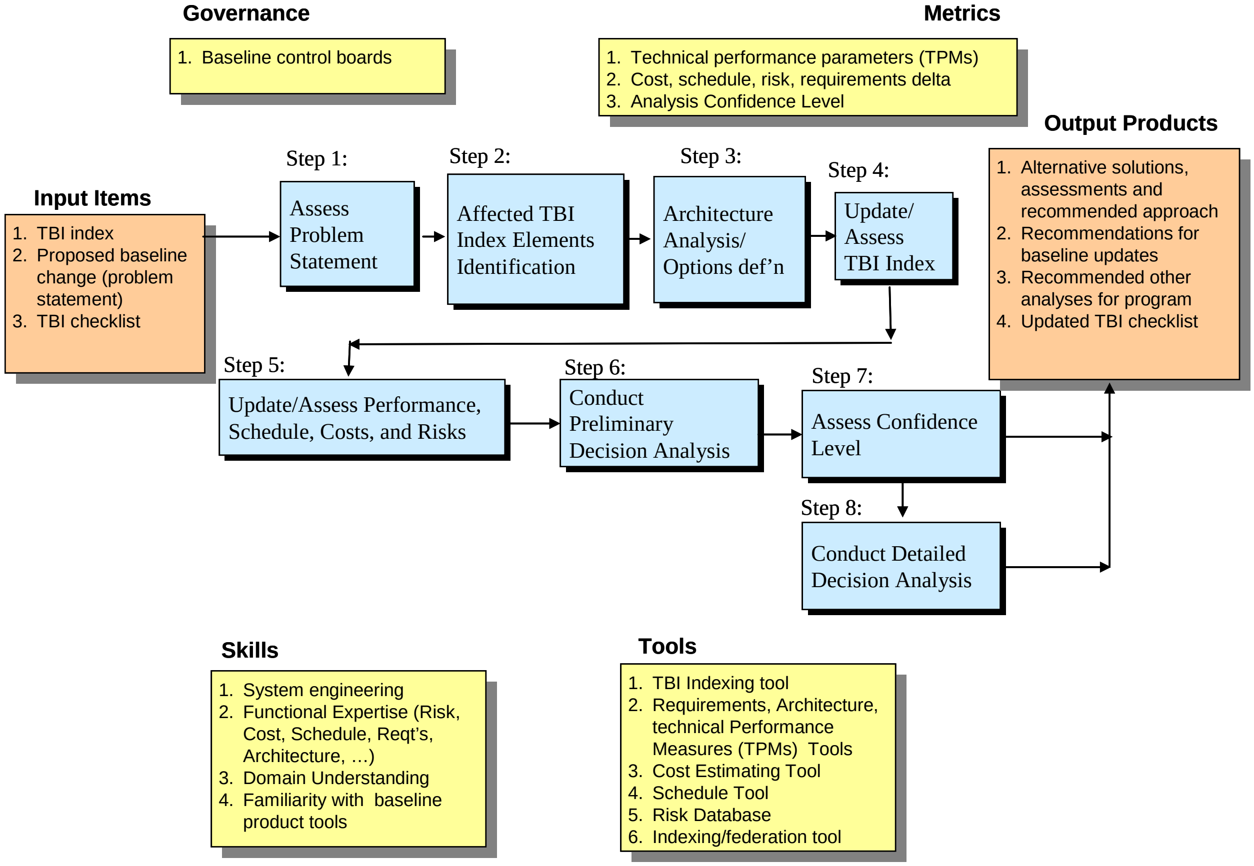


Figure 7. SOP#5 – Perform Baseline Impact Analysis

SOP #6– Baseline Reporting

Program decision makers will need regular access to TBI information. This process will generate metrics and reports to support both periodic and as needed SE&I decision making. This process provides TBI metrics and reports to program decision makers. Inputs to this process include the four program baselines (cost, performance, schedule, risk), the TBI Index, the overall program roadmap, the results of analyses for proposed changes to the system, recommendations from analyses for baseline updates, recommendations from analyses for the need for more detailed analyses, and the program's performance measures. All appropriate data will be formatted in a form that supports an integrated view of the impacts of changes to the system. This reporting may either support periodic functions such as CM boards or ad hoc special requests. The reports will both support the documentation needs of the CM process as well providing on-line reports supporting distributed team needs. The personnel involved in this process will need in-depth skills with whatever tools the program is using to control baselines. This process will also provide a strategic view of how the program is progressing towards its overall roadmap. Figure 8 depicts SOP#6.

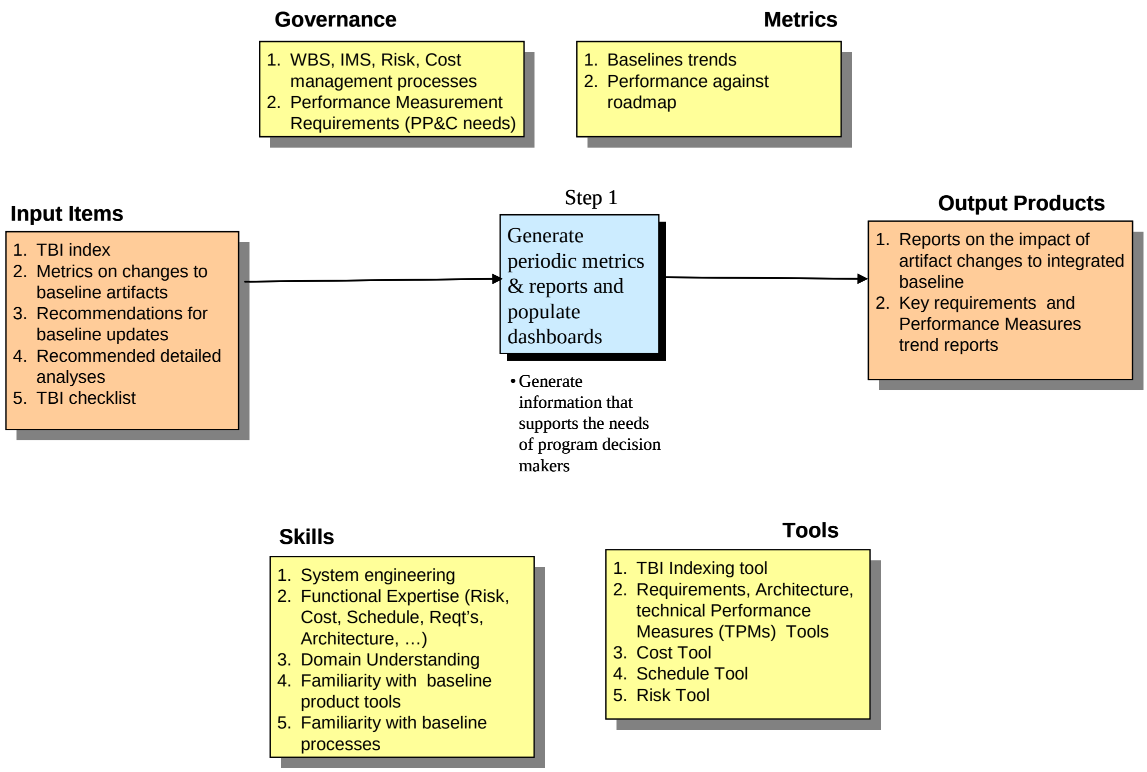


Figure 8. SOP#6 Baseline Reporting Workflow

TBI Applications

The TBI methodology is new and therefore does not have a substantial record of past performance. However, it has been successfully tested and prototyped to validate the feasibility of physically linking the baselines and obtaining the desired results. In addition, the methodology has been employed to various degrees on some very complex system programs with some promising initial results. One example is the Transformational Satellite Communications System (TSAT) Program. The complexities of this system are shown in Figure 9. For this program, we linked data from all the Program baselines using a product-based TBI™ Index in order to assess work activities and technology across the space, terminal, control, legacy segments as well as across all systems engineering efforts. When faced with funding reductions, TBI™ processes enabled the TSAT SE&I team to identify the impact of removing specific capabilities leading to improved decisions about mission and architecture.

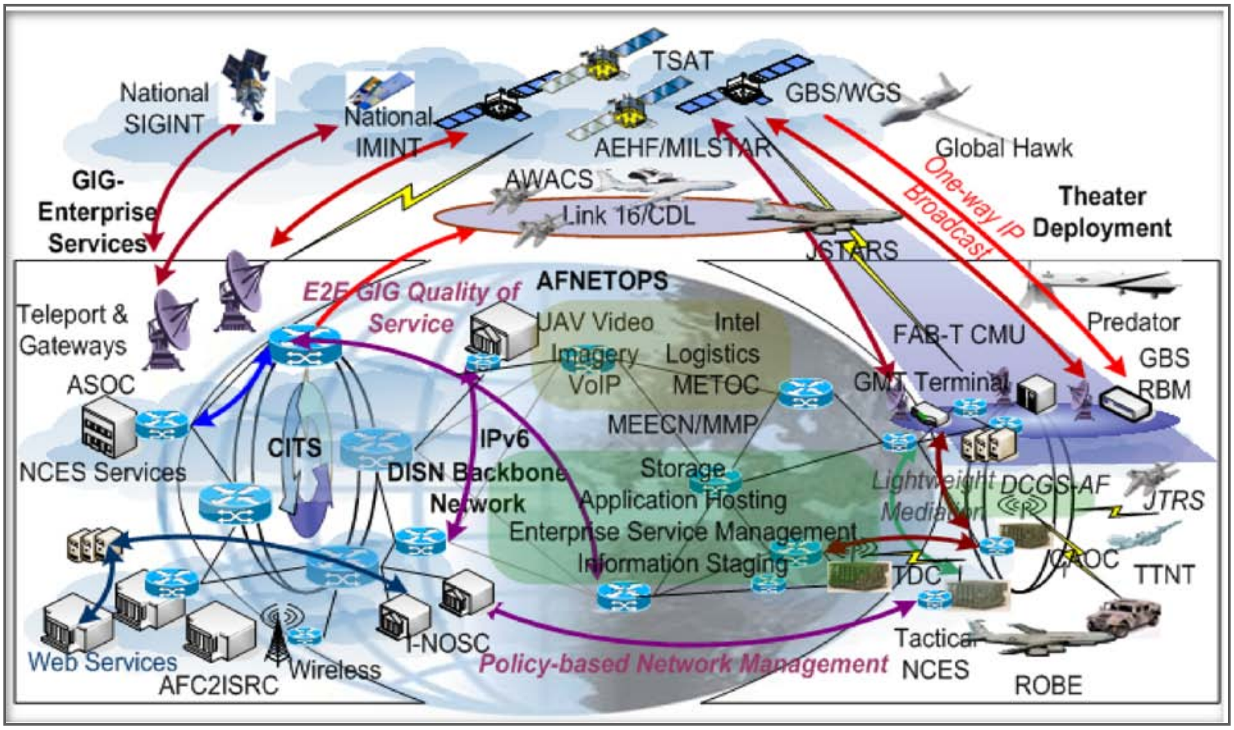


Figure 9. Transformational Satellite Communications Systems (TSAT)

Another application of TBI still under development is in support of the NASA Constellation Program. The objective of Constellation is to replace the Space Transportation System (STS) with a new system of vehicles to transport crew to the International Space Station (ISS), then to the Moon, and eventually to Mars. This a very complex system of systems that includes crew capsules, Orion, multiple rockets for LEO including Ares 1 for Orion and Ares 5, a new heavy lift rocket for cargo, the Earth Departure Stage and Altair, the Lunar Lander. The Program also includes new and upgraded ground processing facilities and new mission control and training systems. One enabler to achieve mission success for a program of this complexity is the creation and maintenance of an integrated set of performance, schedule, cost, and risk baselines to understand the inter-relationships among them which facilitates structured trade studies of alternative mission capabilities and design approaches. The integration of the Constellation baselines is a difficult challenge for two primary reasons. First, the baselines are owned by different organizations and are managed by different support contractors. Second, the initial schedule baseline needed some improvement to facilitate successful linking to the performance baseline. We have determined that a majority of the baselines are sufficiently structured to allow their linkage without much modification. Only the Integrated Master Schedule was not suitable for linking to the other baselines because it is milestone-based versus product-based. Milestone-based schedules do not have the necessary detail to connect technical requirements, product costs, or risks to scheduled activities. The Program has placed a lot of effort in improving the initial baseline over the past year and significant progress has been made. To date, the effort to link the program baselines using TBI has been funded through investment by Booz Allen. First, we created a system hierarchy diagram to use as the foundation for the TBI Index. We then used a COTS software tool, Enterprise Elements (EE), to link the baselines. The user interface screen for our EE tool is shown in Figure 10. The EE tool serves as a front end for an Oracle data base that contains the baseline data. The linkages between the baselines were created and linked using EE.

Figure 10. User Interface Screen for Constellation TBI Tool

Each icon on the screen can be selected by the user to enter portion of the data base that contains the depicted systems data. We developed numerous dashboards using the tool the display the data and metrics associated with the data. Figure 11 shows a sample result of our TBI CxP pilot. It depicts the proportion of technical requirements, costs, and risks attributed to each of the CxP projects. While no definite conclusions can be drawn from these initial results, it does highlight potential areas for investigation. For example, EVA, with only 1% of the budget, comprises 10% of the entire Program's technical requirements and 9% of the risk. This may warrant further investigation to ensure proper management attention is being placed on the EVA Project. With only 1% of the cost, there could be a danger of overlooking EVA's impact to the Program.

Constellation Program

	Program Integration	Orion	Ares 1	EVA	Mission Ops	Ground Ops
Technical	0	40%	15%	10%	19%	15%
Schedule	*Structure of current Cx IMS does not allow linkage with other baselines*					
Cost	4%	32%	39%	1%	7%	15%
Risk	23%	19%	18%	9%	10%	13%

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Figure 11. An Example Initial Finding of TBI on the Constellation Program

In an effort to make TBI an integral part of the Constellation Program and to reap the real benefits of using TBI for significant analysis of alternatives as Program proceeds, we have been working with the Program to identify requirements for a data aggregation effort that will control and disseminate the authoritative sources of program data. We have integrated our requirements for linkage of the baselines into the overall requirement set for this effort. As this comes to fruition, the maintenance of the cost, schedule, and risk baselines will be accomplished by the established program controls team with minimal increased effort. Our SE&I team will then be able to maintain the performance baseline and conduct the analysis portion of the methodology using the linked authoritative data to provide program management with more informed decision recommendations.

TBI Benefits

A major benefit of TBI is in the process of linking the baseline artifacts itself. This requires a minimal level of maturity and a common structure in the baseline artifacts to allow cross-referencing. The increased consistency across the artifacts allows them to be maintained more efficiently with less reconciliation. Through the linking process, deficiencies, inconsistencies, and gaps in the baselines quickly become apparent, enabling managers to address them at an early stage, uncovering potential program issues earlier. TBI provides a consistent technical, cost, schedule, and risk infrastructure for more accurate evaluation of program performance, trades, and proposed changes resulting in more effective management decisions.

BIOGRAPHY

Gary Brown currently serves as the Booz Allen Functional Manager for NASA Systems Engineering including work at 7 NASA Centers. He is also the Program Manager for the Constellation Technical Support Contract which provides SE&I and T&E services to the Constellation Program. Gary has a BS degree in Aeronautical & Astronautical Engineering from Purdue University and a Master’s Degree in Space Science from the University of Houston Clear Lake. Gary has received numerous awards over the years including the Space Flight Awareness Award for leadership for his role in the Shuttle return to flight effort. Gary is an INCOSE Certified System Engineering Professional (CSEP) and he is also the Systems Engineering Technical Chair for the local AIAA chapter. He and his wife, Mai Huynh, have four children named Velocity, Jubilee, Apollo, and Mercury.

Acronym List

AIAA	American Institute of Aeronautics and Astronautics
CM	Configuration Management
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelve
CSEP	Certified Systems Engineering Professional
CxP	Constellation Program
EE	Enterprise Elements
EVA	Extra-Vehicular Activity
IA	Information Assurance
ID	Identify
IMS	Integrated Master Schedule
INCOSE	International Council on System Engineering
ISS	International Space Station
KBE	Key Baseline Elements
LEO	Low Earth Orbit
MOA	Memorandum of Agreement
MS	Microsoft
NASA	National Aeronautics and Space Administration
NDA	Non- Disclosure Agreement
NGO	Needs, Goals and Objectives
OCI	Organizational Conflict of Interest
PM	Program Manager
POC	Point of Contact
RISC-IQ	Risk Integrated with Schedule and Cost – Intelligent Quantification
SE	System Engineering
SE&I	System Engineering and Integration
SME	Subject Matter Expert
SOP	Standard Operating Procedure
STS	Space Transportation System
TSAT	Transformational Satellite Communications System
TBD	To Be Determined
TBI	Total Baseline Integration
TM	Trade Mark
TPM	Technical Performance Measure

WBS	Work Breakdown Structure