AEROSPACE REPORT NO.
TOR-2011(8591)-18

Supplier Risk Evaluation and Control

June 1, 2011

Susan E. Hastings[1] and Colon Gardner[2]

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[2]The Boeing Company

Prepared for:

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Contract No. FA8802-09-C-0001

Authorized by: Space Systems Group

Developed in conjunction with Government and Industry contributions as part of The U.S. Space Programs Mission Assurance Improvement workshop.

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Executive Summary

Given the percentage of work outsourced by the prime contractor, significant risks exist for all space programs of undetected technical and product quality issues within a prime contractor's supply base. This product will challenge existing practices for supplier risk identification and control, identify and document risks, and explain appropriate management to reduce the risk of undetected technical and quality issues. This product covers several necessary steps and many of the challenges that the prime will face in managing the supplier. Guidance is provided to help the prime minimize the risk at the supplier level.

This TOR will introduce a number of models and concepts that are intended to provide a framework to understand the sources of technical and quality risk and to assure the prime contractor has clearly assigned the appropriate expertise to the supplier interface. Not all suppliers are the same and each may have a unique capability. There are many daily business decisions that suppliers make that could affect the products they provide.

Two supply base models are introduced for analyzing the supply base with segmentation techniques. The models provide an overview of the supply base that frames the specific activities involved with managing outsourced products. Discussion with these models allows the reader to visualize where they may have technical and/or quality risks within their supply base and what may be done to mitigate the risks.

The Roles, Responsibilities, Accountabilities, and Authorities (RAA) of the prime contractor supplier team are described. Understanding basic concepts of each role will facilitate application of the models provided in the opening section.

The life cycle model focuses on post-award and post-Preliminary Design Review (PDR) activities. We provide some insights on where sources of technical risks are introduced and where sources of quality risks may occur. A careful examination of Engineering Oversight, Manufacturing Readiness, and Verification and Validation are blended with the product life cycle model to emphasize critical functions that should be rigorously maintained. This description highlights the necessary amount of interaction with the supplier as it relates to the prime's experience with the supplier and the supplier related issues and risks. This section also emphasizes that technical requirements are fundamental to success and should be communicated, referenced, and confirmed to be accurate very early in the pre-award process.

The final segment is devoted to the top recommendations for reducing technical and quality risk in the supply base. These recommendations are the top recommendations from the MAIW team based on personal experience as well as input from the Industry panel members.

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1. Scope

1.1 Purpose

Given the percentage of work outsourced by the prime contractor, significant risks exist for all space programs of undetected technical and product quality issues within a prime contractor's supply base. With the reduced volume and diminishing influence of the Department of Defense's (DOD) space prime contractors, and the erosion of an experienced, knowledgeable space program workforce, the risk is likely to increase in the future. This product will challenge existing practices for supplier risk identification and control, identify and document risks, and explain appropriate management to reduce the risk of undetected technical and quality issues. This document is unique in its focus on identification of gaps in lessons learned and in existing processes that result in recurring challenges.

1.2 Application

This document is designed primarily as a guide for supply chain managers at prime contractor and supplier facilities, responsible engineers for units, quality representatives, and program managers responsible for integration of the program.

All recommendations contained in this document are targeted for suppliers but also apply to sub-tier suppliers. This document could be used by all space acquisition professionals for internal and external product risk mitigation.

2. Reference Documents

Design Assurance Guide, Aerospace report number TOR-2009(8591)-11, 4 June 2009

Defense Contract Management Agency Prospective Offeror's Guide to: Pre-award Surveys; http://guidebook.dcma.mil/42/prospective_offeror.htm

EXECUTIVE, The Academy of Management, "Consider Both Relationship and Substance when Negotiating Strategically," 1989, Vol. III No. 1, pp 37-48

Flight Unit Qualification Guidelines, Aerospace report number TOR-2010(8591)-20, 30 June 2010

Guidelines for Space Systems Critical Gated Events, Aerospace report number TOR-2009(8583)-8545, 09 May 2009

Quality Assurance Requirements for Space and Launch Vehicles, Aerospace report number TOR-2005(8583)-3859, 1 December 2005

Objective Criteria for Heritage Hardware Reuse, Aerospace report number TOR-2010(8591)-19, 30 June 2010

Program and Subcontractor Management, Aerospace report number TOR-2008(8583)-7731, 11 March 2008

Reuse of Hardware and Software Products, Aerospace report number TOR-2009(8546)-8604, Rev. A, 27 January 2010

Space Supplier Quality Issues & Collaborative Solutions, Aerospace report number TOR-2009(8591)-1. 03 July 2009

Systems Engineering Leading Indicators Guide; EPI 270-20, Rev. 2.0; January 29, 2010

Space Vehicle Test and Evaluation Handbook, Aerospace report number TOR-2006(8546)-4591, 06 November 2006

Technology Readiness Levels: A White Paper, NASA, Office of Space Access and Technology, Advanced Concepts Office.

World Class Supply Management: The Key to Supply Chain Management, Burt, David N., Dobbler, Donald W. and Starling, Stephen L. 7th ed., McGraw-Hill, Boston, MA

Proactive Procurement: The Key to Increased Profits, Productivity, and Quality, David N. Burt, January 1984

3. Definitions

Concept of Operations (CONOPS): A description of the system's intended operations, to include launch, deployment, initialization, mission execution, maintenance functions, sustainment, and operating environment considerations.

Critical Design Review (CDR): Evaluates the detailed design and the detailed build-to design for each configuration item (CI) and the aggregate of the CIs to determine if the design meets the allocated functional, performance, and Specialty Engineering requirements. CIs include hardware and software. The CDR also is used to evaluate whether the design can be produced and verified, and is compatible with interfaces, facilities, and personnel. All risks associated with the product design and manufacture should be identified and assessed, and should have mitigation plans established.

Customer: The buying organization, often the U.S. Government, who initiates the contract with the prime.

Federally Funded Research and Development Center (FFRDC): Federally funded research and development centers are unique independent nonprofit entities sponsored and funded by the U.S. Government to meet specific long-term technical needs that cannot be met by any other single organization.

First Article Production: First article includes production models, initial production samples, test samples, and pilot model. Approval of the first article involves testing and evaluating the first article for conformance with requirements.

Gated Process: A review in the product life cycle where technical maturity is assessed and the risks associated with the product and proceeding on the current product path are assessed and communicated to the product's customer.

Illities: Requirements other than functional, such as adaptability, availability, maintainability, manufacturability, predictability, produceability, reliability, safety, security, and survivability.

Integrated Product Team: Cross-functional team formed for the purpose of delivering a product for an internal or external customer. Includes representatives of technical, manufacturing, business, and support functions critical to developing, procuring, and supporting the product.

Major Redesign and Requirement Changes (Major Mod): Corrective redesign and requirement changes for a component are defined as "major" if the test article, after the changes, violates one or more of the commonly used ground rules for qualification by similarity. A major modification requires a new drawing number.

Minor Redesign or Rework (Minor Mod): A "minor" redesign or rework is one that does not fit the definition for major redesign or significant rework. A minor redesign may involve no parts replacement, such as tuning a system by adjustable devices. A minor rework may also involve replacement of an easily unplugged or detachable part. Examples are changing cable link, lead forming, and bracket shimming. A minor rework may have relatively small effect on the validity of previous tests. Typically this change is annotated by a dash number change to an existing drawing.

Manufacturing Readiness Review (MRR): Determines the readiness of the manufacturer to proceed with manufacturing of the product. This event is sometimes referred to as the Build Readiness Review (BRR) or Production Readiness Review (PRR). The software architecture readiness review is analogous to the MRR and is conducted at the completion of the software development planning and architecture definition.

Prime: The organization that has a contract directly with the U.S. government or buying organization.

Preliminary Design Review (PDR): Evaluates the technical adequacy, progress, and risk resolution for the selected design-to approach for all CIs and establishes a configuration baseline down to the assembly level. For software, the software team evaluates the requirements and the maturity to ensure that all phases of the system development lifecycle are incorporated and supported in the design. Establishes functional and physical compatibility of the interfaces among and between the CIs. Demonstrates the design compatibility with the performance, specialty engineering requirements, and the adequacy of the top-level design, testing approach, and CONOPS. The supplier proposal risk should be captured in the risk management process. Supplier risk identification, mitigation, and resolution are the emphases at this point of the program lifecycle.

Product Engineering: An engineering discipline that deals with both design and manufacturing aspects of a product.

Qualification of Flight Unit Hardware: Flight unit qualification is the formal verification (by tests, analyses, inspections, demonstrations, and/or similarity) of design requirements including margin, product robustness, and workmanship. Details of qualification can be found in Aerospace report number TOR-2010(8591)-20, *Flight Unit Qualification Guidelines*, June 30, 2010.

Qualification by Similarity: An approach to apply the qualification history (test, analysis, inspection, and demonstration) of a previously used hardware item to meet the qualification requirements for reusing that hardware, or similar hardware, on a different system or mission. Qualification by similarity requires two evaluations: (1) review of the Qualification Data Package and flight usage record of the previously used hardware item, and (2) verification of the similarity between the previously used hardware and the current hardware in terms of performance and functional requirements, environments, design (including parts, materials, and processes), manufacturing, and testing. Qualification by similarity is not appropriate for software applications.

Recurring Production: An ongoing production that is subsequent to successful first article production.

Roles, Responsibilities, Accountability, and Authority (RAA): Clearly defined expectations for key roles on the supplier management team. Typically, the full scope of the roles, responsibilities, authorities, and accountabilities of these key roles are documented in the prime's command media.

Software Engineering: The set of activities involved in software products development. Software engineering may include new development, modification, reuse, reengineering, maintenance, or any other activities that result in software products. Software engineering includes the development of firmware, which is a hardware device hosting read-only computer instructions and/or computer data.

Sub-tier Supplier: All organizations that are tasked by a supplier to perform a portion of the required effort in the contract between the prime and the supplier.

Supplier: An organization tasked by the prime to perform a portion of the required effort of the contract between the buying organization and the prime. This also includes inter-division work transfers and product centers within the prime.

Supplier Management Team (SMT): Cross-functional team empowered to plan, lead, and manage supplier activities for the program. The SMT works on behalf of the program manager to:

- Direct project activities, manage risk, make trade-off decisions, and resolves issues.
- Negotiate resource needs and assignments.
- Act as a communication focal point with the supplier.

Technology Development: Research and development of new technology. Technology development activities span the range of technology maturity from observation of the basic principles in a laboratory to proof-of-flight equipment operation in the intended environment. Technology development may be required when existing technologies are used in a new way or are modified.

Test Readiness Review (TRR): Verifies that the program is ready to proceed with the formal testing. Typically held as a series of events prior to each round of testing, such as Baseline Integrated System Test (BIST). Each software build product delivered to either internal or external users has a separate TRR.

Units: A functional item that is viewed as a complete and separate entity for purposes of manufacturing, maintenance, or record-keeping. The analogous term for software is Computer Software Unit (CSU) and typically is a well-defined function within a Computer Software Configuration Item (CSCI) (e.g., Kalman Filter CSU within the Navigation CSCI).

4. Assumptions

This document is intended only for addressing hardware risk activities and is intended to supplement the existing command media. While software supplier risk is mentioned in two areas, this document does not address guidance for reducing risks for programs with software and firmware. Many supplier products have embedded software that is crucial to their operation and satisfaction of mission requirements (e.g., star trackers). As such, software deserves the same scrutiny and rigor as hardware risk management and control. This product provides an introduction to the software risk evaluation and control.

Additionally, this document does not address source selection procedures or the risk management process and procedures at the prime contractor. Existing source selection processes and risk management processes at the prime contractor were assumed to be adequate.

Existing best practices for acquisition and program management are well documented elsewhere. This document refers to established documents that describe existing processes in detail and limits discussion of existing processes to a short description or checklist. Please refer to the detailed references for a more complete explanation of existing practices or processes. The emphasis of this report is supplier technical and quality risk identification and recommendations for mitigation techniques.

5. Introduction

During the development and production phases of a typical space program, the performance to plan of numerous first, second, and lower sub-tier suppliers is critical to the success of the prime contractor's performance to its obligations to the customer and end user. The context of this Mission Assurance Improvement Workshop (MAIW) work product is to improve risk identification, assessment, and mitigation as well as to avoid the late discovery of supplier technical and quality issues. Examples of these issues are:

- Late product quality issue: a unit, component, or part workmanship defect during assembly integration and test which went undetected during inspection points at the supplier. A software discrepancy that escaped detection prior to qualification testing would also be considered a late product quality issue.

- Late technical issue: failure or out-of-specification condition during a unit acceptance test program due to part to part variation, an inadequate design margin or a poorly defined requirement, interface or dataset for software.

- Late technical issue: failure of a critical item or high reliability part during unit life test due to an inadequate or non-perceptive screening test at the part level. For software, this is typically last minute algorithm changes or database updates that were improperly coded and/or tested.

This product covers several necessary steps and many of the challenges that the prime will face in managing the supplier. Guidance is provided to help the prime minimize the risk at the supplier level. The product is not trying to document the risk management processes or methodology. The guidance contained within this technical operating report (TOR) represents a blend of concepts from The Aerospace Corporation, Ball Aerospace and Technologies Corporation, The Boeing Company, Harris Corporation, Northrop Grumman Aerospace Systems, Lockheed Martin Space Systems Company, and Raytheon Company Space and Airborne Systems, and lessons learned through execution of large, complex space programs. During the process of creating this document, senior program managers from four prime contractors participated in panel discussions which provided the basis of recommendations. The composition on the panels represents a breadth of expertise from major program directors, program managers, supplier quality managers, mission assurance directors, quality managers, materials and processes engineering, product engineering, component engineering and supply chain management. The MAIW Supplier Risk Evaluation and Control team thanks the panel members for their support and candid discussion.

The information contained within this TOR will introduce a number of concepts and perspectives regarding the supply base for national space programs. The models and concepts provide a framework to understand the sources of technical and quality risk and to ensure the prime contractor has clearly assigned the appropriate expertise to the supplier interface. Recognizing that not all suppliers are the same, each may have a unique capability that is desired, and there are many daily business decisions that suppliers make that could affect the products they provide. The concepts and models introduced are fundamental methods of supplier management. The models provide an overview of the supply base that frames the specific activities involved with managing outsourced products. Managing the technical and quality risks at suppliers is not a "mechanical" activity, but rather requires specific application of resources unique to each situation. There are no magic secrets that guarantee success; no perfect tools that are readily available or proven methods that will promise that no technical and quality risks will occur at the supplier or after the product or software is delivered to the prime. The information provided describes learned skills that can be mastered and may help the reader to identify the technical risks and fundamental methods to mitigate them. The information discussed in this product is as much about leadership and management of the supply base as it is about concepts and

business practices. Understanding the business models and developing strategies from these models is the objective.

This TOR primarily focuses on the period of performance post contract award and completion of the subcontracted product design. This timeframe is emphasized because the importance of developing robust and stable requirements early in the program and supporting subcontracts has already been recognized across the U.S. space programs enterprise. It includes recommendations for the prime contractor's supplier interfaces after the design phase across a range of contracting arrangements. We believe this focus will have significant value to the many engineers, project managers, quality professionals, and supply chain professionals who are being challenged to deliver high quality, highly reliable, space qualified products to ongoing and future programs long after contracts are awarded and product designs are completed.

Section 6 introduces two supply base models to establish methods to analyze the supply base with segmentation techniques. Expanded discussion using these models will allow the reader to visualize where they may have technical and/or quality risks within their supply base and what may be done to mitigate the risks from being a late technical and/or quality issue. The first model is a supplier segmentation matrix (Figure 1) and can be used to define the demographics of a supply base. For the past three decades, supply chain management professionals have modeled the supply base to identify opportunities for reducing the transactional cost for their organizations. The simple premise with this modeling technique is that the number of suppliers in the supply base is proportional to the prime contractor's transactional costs. In other words, the more suppliers in the supply base, the higher the transactional cost.

Prime contractors must have support staff to verify and maintain systems with their flight suppliers. The support staff includes supplier quality representatives, source inspection representatives, field engineering, product engineering, specialty engineering, procurement agents and buyers, financial auditors, and others. Transactional costs also include support personnel and systems that each supplier requires to manage the supply base. Understanding this dimension in the overall business model is fundamental for the reader to grasp the concepts of where technical and quality risks may be introduced in the supply chain.

The second model will provide a supplier product classification quadrant (Figure 2). While similar to the supplier segmentation matrix, this model addresses a multi-dimensional analysis of subcontracting methods and supplier-developed products. This section also examines "Build-to-Print" contracts where the prime contractor is responsible for the engineering and "Build-to-Specification" contracts where the supplier is responsible for the engineering. Each contracting method presents different types of technical and quality risks, and the primes must decide what methods they will implement. The second dimension of the model will apply product segmentation of "Off the Shelf" or "New Product/Development." These two models provide the reader with an overview of the space supply base and associated technical and quality risks.

Section 7 addresses the human element of subcontracted product life cycle. The prime contractor roles are diagrammed and recommended guidelines are provided for each function. The purpose of the section is to present a map of various functions within the supplier team in the subcontract relationship. We will provide fundamental concepts, philosophies, and an outline of Roles, Responsibilities, Accountabilities and Authorities (RAA) of the proposed team members. The focus will be on the basic role of engineering. If the reader understands the basic concepts of each role, they will be better able to apply the concepts with tools or techniques provided in the opening section.

Section 8 presents a product life cycle model. This life cycle model focuses on post-award and post-Preliminary Design Review (PDR) activities. Insights are provided on where sources of technical

risks are introduced and where sources of quality risks may occur. The model allows the readers to determine where they may need resources and responsibilities clearly defined to avoid late technical and quality risks. A careful examination of Engineering Oversight, Manufacturing Readiness, and Verification and Validation are blended with the product life cycle model to emphasize critical functions that should be rigorously maintained. These areas of emphasis overlap, and the prime must make sure the team remains consistent and maintains proper records throughout the life cycle. Ensuring the prime's best practice standards are met through these phases is imperative to minimizing the technical and quality risks. These sections will highlight the amount of activity with the supplier as it directly relates to the experience with the supplier and the supplier-related issues and risks. They also recognize that the technical requirements are fundamental to success and should be communicated, referenced, and confirmed to be accurate very early in the pre-award process. Additionally, it is critical that the requirements are re-confirmed after the subcontract award to ensure the supplier has a full understanding of the technical requirements before any work has begun. It is too late to discover misinterpreted requirements at the PDR, Critical Design Review (CDR), or Manufacturing Readiness Review (MRR). Also included in the product life cycle model are the types of subcontracting methods introduced in Section 6.0 to reiterate the areas where the prime needs to focus resources.

The final segment, Section 9, is devoted to the top recommendations for reducing technical and quality risk in the supply base. These recommendations are the top recommendations from the MAIW team and are based on personal experience as well as input from the industry panel members.

6. Supply Base and Subcontract Segmentation Models

There are a number of models that have been developed to depict the supply chain. This section will use two supply chain models that, in conjunction, illustrate elements that the buyer should consider in managing the supplier and help identify how their company's product team may influence the risks with the supplier. The management of the supply chain is a key success factor for business in today's outsourcing environment. An increasing percentage of our space-level products are being produced in the supply base, and each of the major space industry prime contractors maintains extensive supply chain organizations. The supply chain organizations at the prime often perform modeling to better understand the changes they have made to improve efficiency on the supply chain. The first model, Figure 1 in section 6.2, is used to analyze the suppliers' products' level of complexity and the capability in the supply base. The second model, Figure 2 in section 6.3, provides a multi-dimensional examination of the supply base and its capabilities. These two models illustrate the use of analysis techniques to understand where risks may be introduced in the supply chain and where the buyer may want to increase oversight or surveillance. After reviewing the supply base through these two models, the old cliché, "Caveat Emptor"[1] is as prevalent today as it was 100 years ago. With challenges in the sub-tier supply base, control of outsourced processes, counterfeit parts, aging work force, and limited capacity, the buyer and the buyer's product team must take a systematic approach to analyzing their supply base and deploying risk-mitigation actions. The objective of the supply base models section is to provide an overview of the space supply base and give the reader an overall perspective that they can apply for their specific business situation.

6.1 Supplier Segmentation Matrix

The supplier segmentation matrix is used to analyze the supply base. The two-by-two matrix provides an overview of the supply base that permits the evaluation of supplier capabilities and the complexity of the products or sourcing requirements prior to the execution of a plan. The model provides for the assessment of late technical or quality risks via evaluation of the supply chain.

6.2 Supply Chain Analysis Quadrants

A critical challenge faced by most buyers today is the selection of key suppliers that will provide their companies the necessary components, fabricated items, materials, and major subsystems in a manner that will give them a competitive advantage. Often, the purchasing managers analyze the transactional costs with each supplier to better understand where and how they should be conducting business. Operational factors such as quality, delivery, cost, and technical capabilities have influenced the selection process, but the supply base is not always thoroughly evaluated for late technical or quality related issues. Using a supplier segmentation matrix, as seen in Figure 1, illustrates the dynamics within the supply base.

The vertical axis identifies the capabilities within the supply base that often can correspond closely with the value of the purchased items. The horizontal axis identifies the complexity of the product, and it also often corresponds with the complexity of the subcontract. Each quadrant has a different complexity and requires the supplier management team to carefully analyze the framework to understand where the technical risks occur and how to effectively consider the issues in the strategic evaluation of suppliers. To use the supplier segmentation matrix, suppliers must be identified and mapped onto the matrix.

[1]Original legal term in Latin that translates to "Let the Buyer Beware."

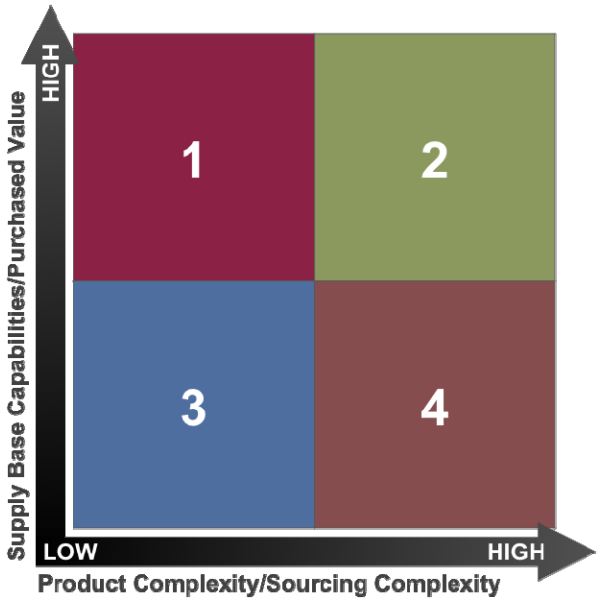

Figure 1. Supplier segmentation matrix: 1. Purchased Technologies, 2. Strategic Alliances, Products and Services, 3. Standard Parts and Commodities, and 4. Directed Purchases.

6.2.1 Standard Parts and Commodities (Quadrant 3)

The standard parts and commodities quadrant deals with components, parts suppliers, minor fabrication items, catalog items, fasteners, Qualified Manufacturers List (QML), Qualified Product List (QPL) and other minor procurements. Because the products in this quadrant are a standard product, the oversight by the prime contractor may be minimal. In the case of standard military electrical components, although the components are complex, there is an established oversight process through the Defense Logistics Agency Land and Maritime (formerly, Defense Supply Center Columbus) that minimizes the required oversight by the prime contractor. For software, this quadrant could include standard math libraries/toolkits and established databus interfaces (e.g., MIL-STD-1553B Digital Time Division Command/Response Multiplex Data Bus).

Other typical supplier attributes or distinctions may include:

- **Sourcing Strategies and Relationship:** Buyer looking for price discriminators, value-added services, rapid delivery. Supplier may provide point-of-use deliveries, kitting services, lead bending or tinning services, etc.; buyers looking to minimize transactional cost.
- **Product and Service Types:** Electrical components, fabricated parts
- **Business Expectations:** Corporate agreements – leverage corporate buying power; supplier should be “best in class”
- **Distribution Channels:** Heavy use of authorized distributors, limited use of original equipment manufacturer

The technical risks could come from many different areas, to include inadequate flowdown of technical requirements, poorly controlled processes, inadequate testing and screening, prohibited

materials, and others. The prime must have adequate incoming inspection and screening processes to identify nonconforming materials. The prime should also have a robust test plan at the part, unit, and system levels that will capture any latent defects. Recommendation number 7 under section 9.7 highlights actions to mitigate these problems.

6.2.2 Purchased Technologies (Quadrant 1)

The purchased technologies quadrant includes suppliers that have mature product lines and provide high-quality products or services. These suppliers have technologies that make them best in class for the product or service they provide. They have a track record of success and should be able to provide references if needed to support evaluations. For software, this quadrant could include processor board support packages and well-known operating systems (e.g., VXWORKS).

Other typical supplier attributes or distinctions may include:

- Sourcing strategies and relationship: Buyer should want to be a preferred customer. Very good working relationship with good cooperation and communication channels
- Product and service types: Assemblies, testing, can also have system integration and contract manufacturing
- Business expectations: We win – You win versus long-term agreements; year-over-year cost improvements; expect a best-value for quality, cost and schedule
- Distribution channels: Original equipment manufacturer, contract manufacturing, very little use of distributors

Primes must also make sure the supplier is managing the sub-tier suppliers in this quadrant. Technical and quality risks come from being too complacent with the suppliers. On occasion, the supplier is not large enough to have the quality systems in place that fully capture all the sub-tier evaluations. The prime must evaluate the supplier's ability to manage the sub-tier supply base at all levels and consider that capability in their oversight approach. Watch for supplier's use of outsourced processing and be mindful of how well it is controlled. Primes should institute controls for supplier's use of outsourced facilities. This may include approval of the outside processing facility, approval of its procedures, and verification of performance capabilities. If this approach is used, the prime must perform periodic assessments at each processing facility to verify the processes are within control limits. Maintaining some oversight is critical for the prime to prevent quality issues from occurring. Recommendation number 9 under section 9.9 highlights actions to mitigate these problems.

6.2.3 Directed Purchases (Quadrant 4)

The directed purchases quadrant is often the most difficult quadrant to work with supplier relationships. As stated in the quadrant's title, these are often single or sole-source arrangements. Engineering may have directed the procurement because of the technology being acquired, based on previous history with the supplier, or because it was the quickest alternative to support the program. Suppliers in this quadrant often have a technology that the prime must have and is only available from this one source. Despite the familiarity the prime may have with this supplier, it is essential that the buyer maintain accurate configuration control on the procurement request, statement of work, and all of the contractual documents. Subcontract management will focus on quality and schedule, but good engineering oversight is required. Engineering oversight must focus on design reviews to ensure all requirements are adequately met and that they are deliverable. The MRR and regular product reviews are important to identify out-of-family behavior, non-compliances, and root causes. Close engineering

oversight is often difficult because the supplier may be the only provider of a particular technology, owns the intellectual property, and may be unwilling to share the details of processes and designs. Early understanding of the potential technical and quality risks is critical. For software, this quadrant could include an entire payload processing system that is embedded within new technology sensor systems highly favored by the customer.

Other typical supplier attributes or distinctions may include:

- Sourcing strategies and relationship: Strategy must be for the specific supplier. Working relationships are typically an "arm's length" relationship. Supplier is not willing to share much information. Communications channel is typically formal. Internally, prime should drive engineering to develop standards that will not lock the sourcing into this quadrant. Redesign options should be explored at each sourcing opportunity.

- Product and service types: Unit-level assembly and testing.

- Business expectations: Buyer wants to develop competition, buyer desires long-term agreements for cost and schedule objectives.

- Distribution channels: Original equipment manufacturer, very little use of distributors.

Outsourced processing and the sub-tier supply base are major concerns with this quadrant as well. Another major area of concern with single or sole-sourced suppliers is the stability of their technical staff and key employees. Loss of a key employee can be catastrophic to the product quality if the manufacturing processes are not well understood and documented. Challenge all qualification by similarity in this quadrant. Maintaining qualified workforce is a challenge for all industries as the U.S. workforce moves into the post baby-boomer workers. Recommendation number 2 under Section 9.2 highlights actions to mitigate these problems.

6.2.4 Strategic Alliances, Products and Services (Quadrant 2)

The upper-right corner quadrant, strategic alliances, products, and services is usually the most cooperative supplier relationship. This quadrant has significant technology content and often has long-term partnering agreements. The companies may even cooperate in technology development and often team for major government and commercial campaigns. Suppliers in this quadrant have advanced quality systems that are capable of managing their sub-tier supply base. For software, this quadrant could involve suppliers located at the prime's facilities with intimate knowledge of the overall software structure, interfaces, processes, and support tools.

Other typical supplier attributes or distinctions may include:

- Sourcing strategies and relationship: Partner on campaign strategies, willing to share technologies; may have risk-share agreements. Working relationships are typically very open and even share work as needed to support programs or business strategies. Very long-term relationships are typical

- Product and service types: Spacecraft payload, unit-level assembly and testing

- Business expectations: Parent company alliances, executive council between companies, both parties invest in the technology, supplier had superb design control and processes, both parties team on new designs for "design to cost"

- Distribution channels: Original equipment manufacturer only

Typically the suppliers are carefully selected and are therefore capable of managing the sub-tier supply base. These are long-term relationships and have taken years to develop. However, the prime should evaluate the overall supply quality systems on a periodic basis. Recommendations numbers 7 and 9 under sections 9.7 and 9.10, respectively, highlight actions to mitigate these problems.

6.2.5 Supplier Segmentation Matrix Summary

The segmentation matrix provides the supplier team with a comprehensive analytical view of the supply base. There are many factors involved with source selections, and the decision often requires consideration beyond operational decisions. The team membership roles are discussed in a later section but all team members must fully engage with the sourcing process. Source selection is a fundamental decision that the buyer must make, and it is also one of the most critical. Various supplier performance and relationship factors drive the complexity of the sourcing decision towards a strategic decision.

6.3 Supplier Product Classification Quadrants

The supplier product classification quadrants model describes the types of outsourcing activity, either Build-to-Print or Build-to-Specification, and if development is involved or if the product is off-the-shelf. Each will provide an understanding of who is responsible for the engineering and where the product is in the life cycle of development or mature off-the-shelf product. The following subsections examine each quadrant of the supplier product classification quadrants model, as illustrated in Figure 2.

Consider some of the key issues and challenges for the prime contractor engineering oversight in each quadrant.

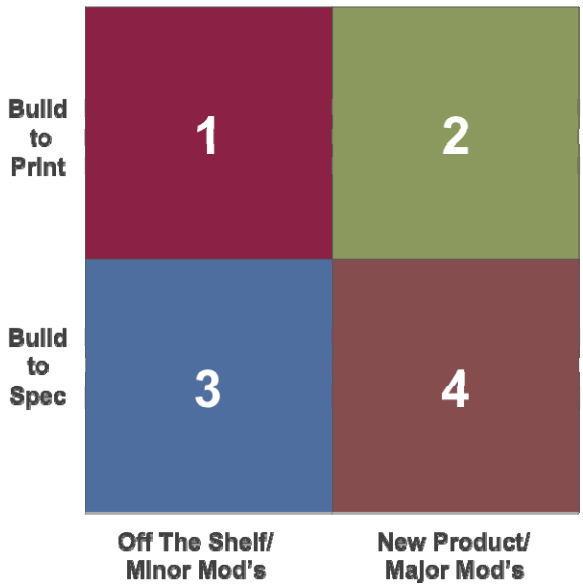

Figure 2. Supplier product classification quadrants.

6.3.1 Build-to-Print and Off-the-Shelf (Quadrant 1)

In the Build-to-Print and off-the-shelf scenario, the prime contractor is responsible for the engineering required to determine the appropriateness of the product and in most cases is buying from the supplier's standard product listings. Some examples of products that often fall into this category are launch vehicle adapters, wave guide assemblies, propulsion tanks, pyros, and passive microwave devices, etc. In most cases for off-the-shelf products, the supplier has produced a specific design and it is offered to all buyers. The prime contractor may use the supplier's product drawings or generate its own using the supplier's drawings or product specification sheet. For instance, the prime may create a source control drawing (SCD) to manage its own unique configuration of an End user Electrical and Electronic Equipment (EEEE) component. Involving the prime contractor's engineering should help mitigate the known configuration risk, but it is important to consider what else could occur. The prime contractor is responsible for the engineering of the overall system. What happens when the supplier makes a minor design or process change and uses a qualified-by-similarity rationale for the change? Changes materials? What information or data does the prime contractor's engineering need in order to accept this analysis or recommendation? What happens when the supplier moves to a new, improved facility? What is required to ensure manufacturing processes are controlled and produce a product that meets the requirements? What is required to ensure quality assurance processes are controlled and that any needed changes are appropriately addressed with the prime? Is it the same product as previously qualified and will the performance be the same in the prime's application? Recommendation number 3 under Section 9.3 highlights actions to mitigate these problems.

For software, Build-to-Print and Off-the-Shelf involves the "as-is" reuse of existing code. Does the new application have any functionality that was not envisioned by the original design? Can the new application be tailored only by database changes to the legacy software? How re-useable are the unit and qualification test cases?

6.3.2 Build-to-Print and Development (Quadrant 2)

In the Build-to-Print and development scenario, the prime contractor develops a product with a supplier. The prime is responsible for generating the engineering and the supplier provides technology and capability of producing the product. What assumptions has the prime made about the supplier capability or process control that has resulted in a needed requirement that is not documented in the prime's engineering records? What could change in this environment from early development to final product? Are there opportunities for subtle changes that may go unrecognized? Will they have an effect on the final product? Strong process control is mandatory and careful reviews and assessments are keys to the successful production and sell-off. Again, another major area of concern will be the stability of the supplier's technical staff and key employees. Loss of a key employee can be catastrophic to the product quality if the manufacturing processes are not well understood and documented. Recommendation number 2 under section 9.2 highlights actions to mitigate these problems.

For software, Build-to-Print and development is analogous to "code to design" where the prime provides the software design (e.g., data flows, hierarchy diagrams, data structures, object-oriented analysis [OOA] models, etc.) and the supplier generates the code and performs software qualification testing to the prime's requirements. What is required to ensure the software configuration is controlled? Is the new application dependent on design approach (structured vs. object-oriented design [OOD])? How easily will the new development accommodate minor requirement changes? How adaptable are the unit and qualification test cases?

6.3.3 Build-to-Specification and Off-the-Shelf (Quadrant 3)

In the Build-to-Specification and Off-the-Shelf scenario, the prime contractor is responsible for specifying the requirement and in most cases is buying from the supplier's standard product listings. Examples of units in this category are thrusters, valves, Traveling Wave Tubes (TWTs), star trackers, and gyros, etc. As an Off-the-Shelf product, the design and development engineering have already been completed by the supplier; and the prime is buying the supplier's completed product. The prime must ensure its specification requirements will be met by the supplier's Off-the-Shelf product. The supplier is responsible for the engineering and must maintain the configurations of its products. What happens when the supplier makes a minor design change and uses a qualified-by-similarity rationale for the change? Or changes materials? What if the prime uses the product in a way that differs from the way the supplier intended, anticipated, or specified for application? Recommendation number 1 under section 9.1 highlights actions to mitigate these problems.

When reusing off-the shelf software to satisfy a set of requirements, consider the same questions as "build to print" and "off the shelf." Does the new application have any functionality that was not envisioned by the original design? Can the new application be tailored only by database changes to the legacy software? How re-useable are the unit and qualification test cases?

6.3.4 Build-to-Specification and Development (Quadrant 4)

In this scenario, the prime is responsible for specifying the requirements and the supplier is responsible for the engineering. The prime must ensure that the supplier is applying mature technology, that the supplier capabilities will be able to accommodate the complexity involved, and that the supplier has the ability to transition to production. Since this TOR focuses on post-PDR activities, any required technology development should have already occurred. A thorough pre-award evaluation is highly recommended. The Defense Contracts Management Agency (DCMA) guidebook provides some excellent guidelines for pre-award surveys:
http://guidebook.dcma.mil/42/prospective_offeror.htm

Build-to-Specification and development software is referred to as "code to requirements" and is the most typical scenario for software. In "code to requirement" software, the prime provides relevant sections of the software requirements to the supplier. The supplier develops his own software requirements specification, the software design material, software code, and tests the code through software qualification. Suppliers usually provide a combination of Off-the-Shelf ("reused") code along with new development.

6.3.5 Supplier Product Classifications and the Supplier Relationship

In a supplier relationship, the relationship scenario is likely to fall predominantly within one of the four scenarios described above. However, there will generally be some facets of each scenario that will become evident over the period of performance. For example, the supplier may be on contract for a Build-to-Specification product where a critical component of the supplier's design may be a build-to-print item from a sub-tier supplier. Delivered software almost always has a mixture of new, modified, and reused software components.

The technical and quality risks can generally be assessed from the subcontractor product classification quadrant as follows:

- Quadrant 1 = Outsourced Production
  - Mature product using existing prime engineering and supplier manufacturing processes
  - Low technical and moderate quality risk

- Quadrant 2 = Teamed Development
  - New product using prime engineering
  - May be used to insert prime developed, new (but matured) technology
  - Supplier provides manufacturing capability and technology
  - High technical and high quality risk
- Quadrant 3 = Production Subcontract
  - Mature product using existing supplier engineering and manufacturing processes
  - Low technical and quality risk
  - For software, this quadrant has the prime purchasing an existing product for a known stable requirement
- Quadrant 4 = Development Subcontract
  - New product or new supplier of existing product
  - Supplier provides engineering – from requirements flowdown to proof of design to technology expertise
  - Supplier also provides manufacturing capability (and technology)
  - High technical and moderate quality risk because of the proof-of-design activities and confidence in supplier
  - For software, the prime entrusts complete development responsibility to the supplier given a set of top-level requirements. This is the most common scenario.

The technical risks can be further defined as engineering and design risks. Likewise, quality risks can be characterized as manufacturing and process risks.

7. The Human Factor

The human factor is a foundational concept with modern supply management techniques that use cross-functional teams. Cross-functional teams have been used since the late 1970s; one of the early examples of cross-functional team approach was described in the 1984 book *Proactive Procurement.* Almost all of the space industry prime contractors use some aspects of cross-functional teams but may identify the team with other names, such as integrated product teams, sourcing teams, quality teams, Supplier Management Teams (SMTs), etc. An important aspect of using teams is that they require a significant investment of human resources. Cross-functional teams are often used for high-valued products and time-critical activities. While these are appropriate applications of cross-functional teams, applying this approach to all subcontracted products helps ensure the appropriate skill sets are involved with the supplier oversight and subcontract management. In 2004, Burt, Dobbler and Starling emphasize that the success of cross-functional teams is dependent on four key prerequisites:

1. Executive sponsorship
2. Effective team leaders
3. Qualified team members
4. Team development and training

Organizations that are developing cross-functional teams should consider using these prerequisites as success factors for their teams. The human factor between the supplier and the prime is an essential and integral element of developing software code to ensure the product satisfies the needs of the prime. Due to the reiterative nature of software, a cross-functional team arrangement is highly recommended.

7.1 The Prime Contractor Roles

The prime contractor roles should be clearly defined from the outset of deploying cross-functional teams such as SMTs. Successful teams have executive sponsors and leaders that are devoted to the team's success. Executive sponsors define the purpose of the teams, provide guidance on how the team will be staffed, and assist the team with defining operating rules along with roles and responsibilities. Many organizations have used teams for decades and may not follow the recommendations of having a team sponsor. If the team is not formally recognized, it is very valuable for the team to define the purpose, staffing plans, and operating rules and define each team member's authority.

Another aspect of the prime contractor roles is that some of the team members focus on contracts and business details, while others focus on the technical and quality concerns. Figure 3 depicts the primary roles of the prime contractor in a subcontract arrangement.

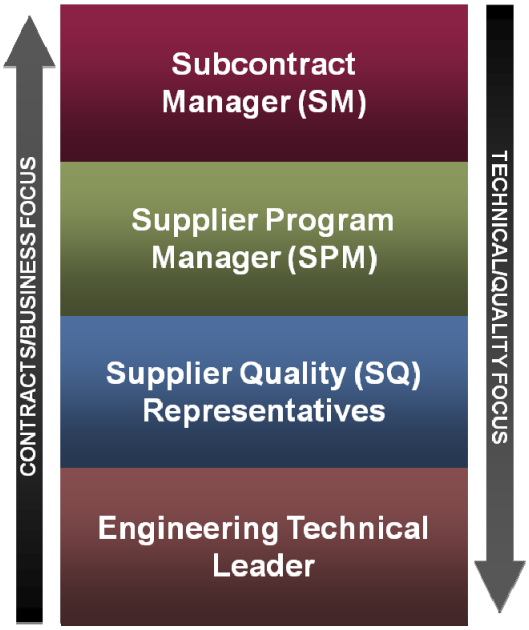

Figure 3. Prime contractor roles.

While the roles identified are not a complete list of the functions that may be involved with the supplier arrangement, these are key roles that are almost always present. The arrows on the left and right side of the diagram illustrate areas of interest that must be managed in the supplier relationship. Having clear communications with the supplier on both the business aspects of the contract and the technical information is critical for a successful contract. The Roles, Responsibilities, Accountability and Authority (RAA) recommendations are discussed in Section 7.2.

7.2 Roles, Responsibilities, Accountability and Authority (RAAs) Guidelines

Assignments for cross functional teams, such as SMTs, are typically additional duties for the team members and in many cases quickly become an overload burden for individuals involved. Defining each team member's RAAs will help the individual understand the role and responsibilities, but does not eliminate the time contention. Just like professional sports teams, not all supplier management teams are created equal. Imbalance can occur when one role dominates the others. The team will function best when each role is balanced and allowed to contribute equally. While studies and recommendations from researchers have helped to minimize the conflict of the team members and their primary function's role, cross-functional teams still struggle with work assignments. In particular, team members have to cope with part-time assignments of key individuals to cross-functional teams. The cross-functional team membership needs to be projected in advance to enable the technically appropriate personnel to be in place when needed.

The RAAs that follow are provided as guidelines and assume that the prime has command media that will define the roles for each function.

7.2.1 **Subcontract Manager (SM) –** Also Known As Supplier Leader, Supplier Management Procurement Agent or Buyer

- Role/Responsibility
  - Manages, directs, and controls the processes for obtaining products and/or services from suppliers
  - Establishes and maintains performance planning through best practices maturity models, such as the supplier management best practices, Capability Maturity Model Integration (CMMI), and Technology Readiness Levels (TRL), as well as Subcontract Manager Plans, and RAA
  - Issues Requests for Proposals, coordinates proposal evaluation teams, evaluates supplier proposals, conducts fact-finding, and negotiates all subcontract requirements, including out-of-scope changes through contract duration
  - Prepares and issues all contractual direction and correspondence to supplier in coordination with the Integrated Product Team (IPT) Lead/Supplier Program Manager (SPM)
  - Participates in supplier Award Fee evaluation process.
  - Measures supplier performance using metrics
  - Coordinates shipments of hardware and software to and from supplier
  - Receives and tracks Supplier Data Requirements List (SDRL) submittals, and transmits official response to supplier, as required
  - Establishes and maintains the official subcontract files
  - Requests audits (technical, cost/price) of supplier proposals
  - Primary interfaces with supplier for addressing all contractual requirements that impact scope, including technical, quality, schedule, cost, data and/or deliverable requirements
  - Integrates activities with internal and external customers and suppliers to fulfill contract requirements

- Authority
  - Acts as an authorized agent of the prime, with responsibility for managing all supplier-related activities and has the authority to commit prime resources through purchase contracts and other agreements with suppliers
  - Supplier contracts management and procurement procedures and government acquisition regulations govern all SM activities
  - Only person who can contractually direct the supplier to begin work
  - Only person who can contractually change the subcontract scope, including technical, quality, schedule, cost, data, and/or deliverable requirements
  - Leads the team in proposal evaluation, fact-finding and negotiations.
  - Only means of contractual communication with the supplier

- Accountability
  - Accountable to the IPT lead and SPM, for supplier contractual performance
  - Accountable to the Business Unit /site SM leader for supplier performance at the business unit or site (i.e., Estimate at Complete (EAC)/Budget at Complete (BAC), Quality, delivery, etc.)

7.2.2 Supplier Program Manager (SPM)

- Role/Responsibility
  - Ensures on time delivery of supplier products and/or services that meet the subcontract technical, quality, cost, and schedule requirements
  - Performs day-to-day coordination with supplier and IPT members relative to technical requirements and provides supplier performance data/metrics to respective IPTs
  - Supports program reviews with respect to supplier performance
  - Performs supplier risk management analysis and associated mitigation plans.
  - Timely development, release, and maintenance of Statement of Work (SOW), Procurement Specification, SDRL drawings
  - Supports bid/proposal effort as well as Configuration Control Board (CCB) related effort
  - Designate individual(s) responsible for preparing technical evaluation of proposals
  - Reviews and approve all technical evaluations prior to submitting to supplier management and support negotiations
  - Participates in Award Fee evaluation process
- Authority
  - Designated by IPT/Team leader as the primary interface between program office and supplier
  - Manages supplier technical, quality, cost, and schedule performance to subcontract requirements
  - May provide technical direction and guidance within the scope of the subcontract
- Accountability
  - Accountable to program IPT for overall supplier performance in support of program requirements, goals, and objectives
  - Accountable to SM for adherence to sanctioned processes and procedures

7.2.3 Supplier Quality (SQ) Representatives

- Role/Responsibility
  - Attends MRRs to provide input to inspection planning
  - Determines application for post-award quality reviews
  - Determines the applicable prime contractor’s quality clauses, surveillance, and inspection plans
  - Reviews purchase orders before issuance for correct quality provisions

  - Works with IPT and technical leads to establish levels of quality assurance at the supplier
  - Performs liaison role between the IPT/technical lead and the source inspectors
  - Processes all supplier nonconformance reports in the prime contractors quality system
  - Approves Nonconformance Report (NCR) closure plans

- Authority
  - Typically the only supplier quality representative that can enter supplier-related nonconformance information in the quality systems
  - Issues supplier corrective action plans to the supplier
  - Approves NCR closure plans

- Accountability
  - Accountable for ensuring supplier quality processes are capable of measuring and ensuring compliance with requirements
  - Accountable that the Supplier Quality data in prime contractor's Quality System is accurate and current
  - Accountable for assisting supplier and prime in requirements clarification
  - Resolution of any Supplier Quality issue within the prime contractor

7.2.4 Engineering Technical Leader

- Role/Responsibility
  - Assumes ownership, responsibility, and accountability for all technical aspects of the procured hardware, software and/or services, including the specialty engineering functions
  - Regular technical interface with IPT members and suppliers to obtain working level data/information. The software technical lead needs a broad combination of software process and specific applications knowledge
  - Maintains technical data file (formal and informal technical data/information)
  - Prepares and maintains the procurement specification
  - Supports all supplier PDRs, CDRs, Test Readiness Reviews (TRRs), Functional Configuration Audits (FCAs), Physical Configuration Audits (PCAs) and Technical Engineering Meetings (TEMs)
  - Performs technical evaluations of supplier proposals
  - Coordinates with and obtains the necessary engineering discipline concurrence and requirements for flowdown to suppliers

- Authority
  - Principal reviewer and technical approver of all SDRLs
  - Represents the supplier at internal prime contractor meetings to ensure technical information and constraints are communicated to the program and back to the supplier

- Accountability
  - Accountable to the IPT/team leader/SPM for overall IPT technical performance

8. Product Life Cycle

In the past 20 years, significant progress has been made with the gated process in the space industry. TOR-2009(8583)-8545, *Guidelines for Space Systems Critical Gated Events*, has provided a common understanding for all primes and suppliers of the expectations at each gated event. The Product Life Cycle section of this document highlights the activities after PDR through final sell-off. It should be noted that, for hardware and software, the activities prior to PDR are especially important because they set the framework for the product development. Poor design decisions can remain latent until well into qualification testing where fixing defects causes huge schedule and cost impacts. This document and Figures 4, 5, and 6 augment TOR-2009(8583)-8545, *Guidelines for Space Systems Critical Gated Events*, with further insights and application of product through the following subcontract perspectives:

- Outsource production – Build-to-Print/Off-the-Shelf (quadrant 1 in Figure 2)
- Teamed development – Build-to-Print/new product or development (quadrant 2 in Figure 2)
- Production subcontract – Build-to-Specification/Off-the-Shelf (quadrant 3 in Figure 2)
- Development subcontract – Build-to-Specification/new product or development (quadrant 4 in Figure 2)

The focus of this section is to identify late technical and quality issues within the supplier product life cycle. It is assumed that the prime's source selection and pre-award processes and reviews are adequate. It is also assumed that the responsible functions are properly involved with the initial reviews and evaluations of the suppliers' technical, quality, and manufacturing capabilities. The focus of this section remains on the supplier product development life cycle and its interface to discover late technical and quality risks in the product life cycle (see Figure 4).

Figure 5 and Figure 6 expand the product life cycle diagram (see Figure 4) to bring in other aspects of managing subcontracted items at the supplier. Note that these figures are meant to clarify the scope of this document and not to define the only way to represent a product development life cycle. The definitions and names of activities in the lower portion of the diagrams can vary between programs and primes. Each of these activities or phases may have periods of large overlap and/or may be performed simultaneously. The criteria chosen for each of the activities found in this document are focused on spacecraft unit-level hardware. As such, they are not meant to imply a formal review, and records may or may not be maintained for these events. It is highly recommended that a well-kept engineering notebook is maintained throughout the product life cycle. The engineering notebook is a single notebook that comprises the chronological series of events for design and development of the engineered product. There are gated events that occur during these activities, such as SRR, PDR, CDR, MRR, and TRR.

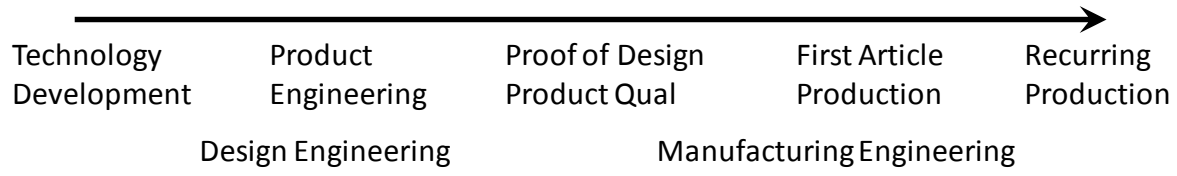

Figure 4. Notional product life cycle.

As noted in Figure 4, these activities overlap and are sequenced to show the order in the design and development process.

The technology development stage occurs early in the product life cycle, prior to establishing the design. The designer identifies the components early in the development process and performs any analysis to establish a baseline design. The product engineering stage will further mature the design through a series of analyses to ensure the design can actually be produced. The designer completes a set of design drawings and specifications for all products and components contained within the unit of the final product during this phase. At this point in the product life cycle, much of the heavy lifting for engineering is complete. All engineering disciplines, including the 'illities (e.g., producibility, reliability, survivability, maintainability, manufacturability, etc.), are performed and evaluated, to include a qualification plan that will be executed in the next phase.

Throughout these activities engineering confirms that the unit requirements meet the overall requirements of the system. Verification activities do not start at the end of the product life cycle but must be planned from the beginning of the product life cycle and incrementally performed to continually lower the risk of unit nonconformance to requirements. Software verification is a process to continuously gain confidence that the software will work as intended by the user. As such, software activities such as prototyping, simulation, modeling, and analysis can be used throughout the development cycle to benchmark and assess expected performance and characteristics. Another critical consideration of the product design phase is "key product characteristics," which are essential for the design to properly perform as intended, as well as ensure that key product characteristics can be verified. Key product characteristics are defined in AS9103 as "the features of a Material or part whose variation has a significant influence on product fit, performance, service life, or manufacturability." Refer to AS9103 for additional details. The design activities ensure the design is meeting its intended use. Good product design includes manufacturing input to the design process to ensure manufacturing efficiency. Manufacturing difficulties should be eliminated or mitigated in the design during the design phase.

All qualifications for components and material must be completed and vetted with the proper quality review boards during this time period and prior to any flight production. First article production triggers the manufacturing areas that they are ready to move into the recurring phase of the program. Close oversight and detail inspection with the engineering team and quality assurance team working together is required during this phase to ensure the proper inspection points are documented and recorded into the planning for the future builds. The recurring production follows with the appropriate checks and balances that are developed in the previous phases. Figure 5 highlights the areas where the technical requirements can typically be discovered and notionally where the verification activities occur. The illustration uses open arrows indicating undefined beginning and end points in this diagram. This is not intended to imply that the contractual requirements are changing throughout the development and production of the unit. It does indicate the occurrence of trades in the lower level requirements of the unit until the design is firmly established and proven through verification.

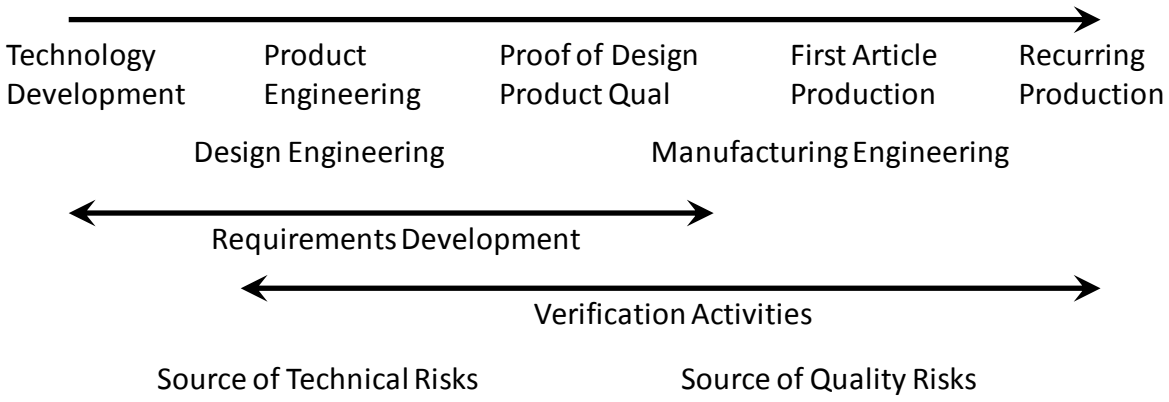

Figure 5. Notional engineering and manufacturing engineering activities.

The cross-functional team identified in the previous section has a tremendous task to remain focused on the integration and readiness of the overall supplier design, manufacturing, and testing capabilities. Additionally, the team must understand the quality system that the supplier has in place and where gaps may exist within the requirements. Recommendation numbers 9 and 10 under Sections 9.9 and 9.10, respectively, highlight actions to mitigate these problems. Another key understanding that must be evaluated at the suppliers is how they manage their embedded software, and outsourced processing at the sub-tier suppliers. In the following explanation, tier 1 supplier is the prime contractor's supplier. Sub-tier suppliers will be suppliers that are providing high-reliability parts, sub-assemblies, fabricate parts, materials, manufacturing services, testing services, software, etc to the prime contractor's supplier. Areas that require focus include the following, at a minimum:

- Parts/hi-reliability (Hi-rel) Components
  - Integrity of approved parts list (APL)
  - Parts qualification
  - Parts screening, lot acceptance and quality conformance inspections (QCI)
- Special (manufacturing) processes
  - Integrity of approved materials and processes lists (AMPL)
  - Material and process qualification
  - Material screening and certification
  - Recurring processes verification
  - Allowable rework/repair processes, penalty testing, inspection points, configuration managements and travelling risk
- Embedded software
  - Software development plan
  - Software verification and configuration management
  - Software quality

- Contracted services
  - Practices of the contracting company (rigorous hiring and screening of candidates)
  - Formal qualifications (including similar work) of those providing the services
  - Expectations of the contracting company (what is acceptable, what is not, etc.)

It is not unusual that late-cycle technical and quality issues are frequently traced to unidentified risks in critical items produced by sub-tier suppliers that later become realized issues at the supplier or prime contractor. Recommendation number 7 under Section 9.7 highlights actions to mitigate these problems.

As mentioned earlier, there are many formal reviews that are not shown here. Figure 6 pulls the subcontract product classifications quadrants displayed in Figure 2 into the product life cycle and illustrates areas that are closely linked by both the activities that are occurring and the dependencies that are required during the design activity itself. The product life cycle illustrates areas that require the technical engineering efforts to lead the supplier activities.

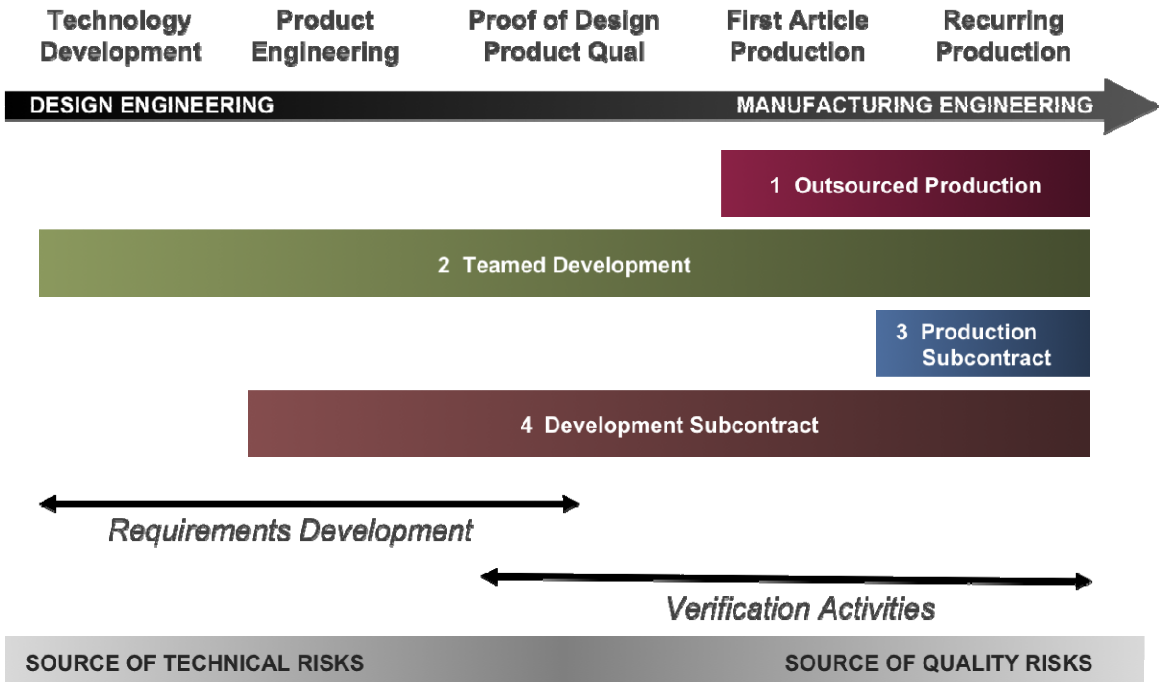

Figure 6. Notional subcontracted product life cycles.

8.1 Engineering Oversight

The purpose of engineering oversight is to reduce or eliminate the engineering escapes or omissions by the supplier as early as possible in the design life cycle, and to ensure design integrity and robustness while maintaining efficiency. Effective engineering oversight provides a truly independent and competent assessment of the engineering drawings, models, analyses, and specifications necessary to physically and functionally describe the intended product, as well as all engineering documentation required to support the acquisition, manufacture, test, delivery, use, and maintenance of the product. Engineering oversight activities need to be unbiased and performed by experts on the technology being acquired to critically evaluate the supplier design and ensure smooth integration into the overall system.

Engineering provides an independent technical review of the supplier and is responsible for monitoring technical development progress, status, and issues. Effective engineering oversight complements (augments and does not duplicate) the supplier's internal and required risk-management process; it does not replace it, nor does it create a parallel risk process. It is a complementary assessment of the inherent risk associated with supplier design elements. The supplier's technical risk identification list is one of the many inputs into the engineering oversight's independent assessment of risk. Engineering oversight activities can range from participation in technical reviews to the use of on-sight engineering representatives depending on the technical maturity of the supplier, the amount of risk the customer is willing to assume, and the severity and number of technical issues.

The subcontract typically includes several technical reviews held at discrete project milestones throughout the product life cycle. These reviews may be formal (e.g., requirements or design reviews) or informal (e.g., working groups, technical interchange meetings). The purpose of the formal reviews is to review the product design, ensure the products are compliant with the subcontract's technical requirements**,** and ensure the supplier can demonstrate the capability of fulfilling its contractual obligation. Effective engineering oversight will produce findings, liens, actions, and lessons learned, and will leverage historical lessons and then follow-through to closure and escalating (if needed) in order to accomplish corrections or recommended design changes. The follow-through is critical to managing the technical risk and keeping the supplier on track to deliver a successful product.

When a redesign occurs, it is often driven by insertion of new technology that increases capability or decreased space, weight, or power requirements. Insertion of new technology into a product design requires engineering attention to ensure progress towards acceptable maturity. New technology often comes with a promise of increased or enabling performance, but it also comes with a new set of risks and issues that may or may not be apparent. Understanding the product quadrant (Figure 2) will help identify areas of risks. New product development is characterized in quadrants 2 and 4. The maturity of the new technology should be considered prior to incorporating the technology into the design. Any technology development that needs to occur after the supplier design has been established is a risk to the program because success in technology development is not predictable. The development timeline and the schedule risk should be considered when developing technologies and the design in parallel. If this is the case, a backup plan that is not dependent on the developmental technology should be carried unless high risk is acceptable to the program. If the supplier design depends on a developmental technology, the program plan must account for that risk, and the engineering oversight role should be to monitor the progress to plan, identify issues as early as possible, and bring attention to the issue so that assistance and resources can be brought to bear.

The technology maturity should be assessed in the context of the current supplier design, system requirements, and integration. Even if the unit has flown in space, if it is used or integrated differently, risk reduction activities will be required to ensure it meets those new requirements. Effective engineering would identify and properly mitigate the risk of reuse in a different design environment. The *Design Assurance Guide*, TOR 2009(8591)-11, dated June 4, 2009, provides additional guidance for Engineering oversight during the design phase.

8.1.1 Engineering Oversight Supplier Assessment

The prime should review the supplier's capabilities, review the supplier's quality management system (QMS), review the supplier's QMS certifications, ask the supplier to identify special processes involved in the production of the end item or its components, and monitor the supplier for changes over time. Supplier quality has the primary responsibility in the cross-functional team model. The SQ RAAs are identified in section 7.2.3. Understanding the supplier quality systems is critical to the success of subcontract products. If engineering design metrics indicate that there are no significant areas needing improvement or of significant risk, engineering oversight can be minimized.

Engineering design metrics that show trending can help predict issues, thus enabling early mitigation, but they must be regularly updated and monitored to be effective. Some examples of design metrics are number of design changes, cycle time, key margins, to be determined (TBD) and to be revised (TBR) burn-down in requirements, or accomplishment in the verification matrix.

The supplier's set of standard processes should be established early in the program and should be contained or referenced within the planning documentation delivered to the prime. If referenced, the standards should be delivered separately. The intent is to establish expectations and avoid surprises or a missed milestone(s). The prime must review and accept tailoring or negotiate an acceptable level of tailoring of the supplier's processes to get an acceptable level of information at the technical reviews. Roles and responsibilities should be defined as part of this review of the supplier processes. These standard processes should be used to establish consistency with the supplier to allow integration of the processes, tracking of metrics, and early identification of issues.

Verification that established supplier processes are being followed is typically accomplished via periodic audits. Typically, the supplier can only be audited to requirements they are contractually responsible to deliver. The audit process can be invaluable for keeping the manufacturing in line with the established processes in order to produce a product consistent with the qualified item. The prime contractor must ensure the supplier quality system remains stable throughout the life cycle of the subcontract. This is critical to prevent late technical and quality issues from occurring on the program. Recommendation number 10, under Section 9.10, highlights actions to mitigate this problem.

8.1.2 Supplier Involvement in Design

Suppliers of a Build-to-Print (BTP) item, quadrant 1 or 2 in Figure 2, have not been part of the design review process, so it is worth reviewing the design with them for disconnects. Consult with suppliers involved in the manufacture of BTP hardware as early as possible in the acquisition to ensure that their manufacturing capabilities and capacities can adequately support the design or any design modifications are identified. Suppliers involved in design and manufacture of build-to-specification hardware, quadrants 3 and 4 in Figure 2, should be assessed for design capability and control, in addition to assessing manufacturing capabilities. Omissions, errors, or other discoveries made by the supplier or supplier management team should be captured in the prime's engineering documents.

8.1.3 Software Activities

Products that contain embedded software may create the greatest risk to a space program for supplier software developments. Defects caused by poorly specified supplier requirements and/or inadequate module testing usually do not surface until hardware and software integration. The integration of hardware and software is typically done after software qualification. By this time, key developers have rolled onto other programs. Debugging and retest at this phase of the program can result in major schedule delays and unplanned costs. Software programs must include a decision process and corrective actions to ensure the software will execute the program mission and objectives. The process should examine the product across the life cycle of the program and implement standards that have a history of providing the greatest success. It is imperative that software quality support be maintained throughout the entire lifecycle to enforce stringent process control. The Aerospace report TOR-2009(8546)-8604, Rev A, *Reuse of Hardware and Software Product,* dated January 27, 2010, provides a decision process for reuse of software which can also provide good risks questions to ask for new software activities. The TOR also contains a decision gate guide and Appendix B, "Software Evaluations Considerations," that will assist software projects.

8.2 Manufacturing Readiness

The Manufacturing Readiness Review (MRR) is a highly detailed check to ensure that design and manufacturing details required for success are in place prior to the supplier commencing with manufacturing. In the notional subcontract product life cycles, shown in Figure 6, the MRR would notionally occur immediately prior to production start of first article production. Manufacturing of the flight article should not begin until the unit is flight qualified. The manufacturing processes are very complex and susceptible to error, particularly when preparation or process control is sacrificed to save schedule or cost. Careful preparation and contingency planning prior to execution of manufacturing can pay dividends in cost and schedule and allow the program to stay on track technically. A checklist for an MRR is included in Appendix B for reference.

- The general practice MRR leaves gaps. Appendix B provides a detailed checklist for performing an MRR. In addition to Appendix B, consider the following to avoid experiencing the same gaps:
  - Experience suggests that while most MRRs are detailed, the level of detail examined is at a higher level than where, and by whom, the work is actually being performed
  - Experience also suggests that MRRs are conducted with a success plan orientation and do not adequately review the failure plan scenario should plans go awry
  - The premise for the MRR guidelines offered in Appendix B is that the "Devil is in the Details" at the operator level – the assembler, the inspector, drawing, shop floor traveler, the Materials Review Board (MRB) process, the production control flow, the front line manager, etc.
  - The tone of the MRR must embrace the pace of the manufacturing environment that spans multiple shifts, staffs, disciplines, and other programs competing for these same resources
  - The MRR guidelines offered in Appendix B identify the framework of a manufacturing environment that is capable of responding successfully to the daily challenges that introduce schedule and cost risk for the program
    - The answers provided to the questions will allow for all parties to understand the full extent of the resources available for successful program execution.
- Risks that are not addressed by the normal MRR process:
  - Scope changes communicated to entire organization
  - Organizational changes
    - Show that staff demographics and estimated attrition are covered sufficiently to meet forecasted requirements
  - Coordination of technical and schedule requirements between multiple disciplines and shifts
    - Identify staff with the critical skills required that could pose a risk to production capacity/capability including management, support functions, and touch labor.

8.3 Verification and Validation of Product Performance

Verification and Validation (V&V) is a risk management approach that builds tasks to define key items that not only show that the supplier's unit is working as needed, but also provides insight into those areas that may lead to higher level of integration issues. These issues or risks should be

followed up with early, perceptive Assembly Integration & Test (AI&T) tasks that allow one to fix any findings before the higher level of integration costs are realized. System simulation at interfaces, hardware-in-the-loop, or rapid prototyping can provide early detection of technical issues and allow corrective actions taken earlier in the integration. Use of the Test-Like-You-Fly philosophy is employed to simulate the flight environment as closely as possible during testing and is intended to uncover problems as early as possible in development, and always prior to launch.

Between requirements flowdown and factory acceptance testing, an incremental V&V process including the entire supply chain should occur to ensure the supplier's product will meet requirements and perform as required in the intended environment. The product life cycle, shown in Figure 6, highlights the importance of verifications activities early in the program. As V&V proceeds, confidence in the supplier's product increases and risk is decreased. Verification is performed throughout the development life cycle:

- Are you allocating requirements to lower-level assemblies to ensure lower risk or lower cost?
- Are critical margins verified with test to destruction? Qualification testing may ensure first pass success at the expense of learning something critical.
- Do you have incremental key inspections and sell-offs (i.e., suppliers, sub-tier suppliers) to meet subcontract needs or mitigate higher level of assembly issues?
- Is the supplier testing, assembling, and operating at the right increments to ensure lower risk at the higher levels of assembly or just where it is convenient?
- Is your AI&T process perceptive to issues at the next level of assembly?
- Are you building perceptive models and/or analyses that continuously get matured with "real" data from the AI&T and are they perceptive to foretell potential future issues?
- Are the high-risk requirements and areas of AI&T noted early, mitigated, and continuously monitored? High-risk areas are things that could dramatically impact program performance, or impact the customer's schedule, cost, or resources.

The prime should consider the higher-level development and/or AI&T to see issues and build contingency, alternate paths, and workarounds. During various levels of integration between unit level and system level, consider measures to mitigate risk at the higher level of assembly and integration as well as interface risks at the lower levels.

- Are the next levels continuously assessing what is really required and where margin exists to help lower-level issues or are they managing the subcontract?
- Are the next levels working opportunities in areas of interfaces and Concept of Operations (CONOPS) workarounds to mitigate lower level issues?
- Are the next levels managing the subcontract for risk?

A TRR should be conducted for every major test. The purpose of the TRR is to ensure the test article, test equipment, facilities, personnel, hardware, software, test tools, predicted performance, and test procedures are in place and ready for the test to proceed. A more complete discussion of testing space hardware is available in the *Space Vehicle Test and Evaluation Handbook*, TOR 2006(8546)-4591, dated November 6, 2006. A complete TRR checklist is available in Aerospace TOR-2009(8583)-

8545, *Guidelines for Space Systems Critical Gated Events*, dated May 9, 2009, and is referred to as a Test Evaluation Campaign Review.

8.4 Requirements Verification and Flowdown

The optimal way to establish a supplier subcontract is with requirements that are complete, accurate, unambiguous, verifiable, and traceable to the requirement sources. The prime should review the supplier subcontract and work with the generators of Product Functional Specifications, Source Control Drawings, or statements of work to ensure that all flowdown requirements are included. The planning for verification should be established at this time in the form of a database or requirements traceability matrix, where all requirements are validated to ensure that when verified, they meet higher level parent requirements and stakeholder needs. The expectation for meeting the requirements should be well understood by the supplier and the prime. Verify, as applicable, that all revisions of mission assurance plans or quality assurance plans are flowed down to suppliers and be aware of any gaps or differences between the supplier's command media and the prime's accepted processes. The prime should have a firm understanding of the supplier's ability to consistently follow its own command media and processes.

A program CONOPS provides an overview of the overall system operation, the operational environment and a requirements matrix to ensure all requirements are addressed either internally or by a supplier. The overall CONOPS is a prime contractor product, and it is useful for providing context to the product the supplier is producing. The CONOPS, developed at a system level, may be too high-level to be meaningful to the supplier and may need to be narrowed to focus on the supplier's product within the system. The CONOPS should cover the total life cycle of the supplier's product and ensure an understanding between the supplier and the prime on what the requirements are, what the interfaces are, and what type of change control will be used. Careful review of the CONOPS by the prime with the supplier will allow the supplier to identify aspects of the intended use that were not considered during design. A review of the CONOPS is routine practice when an item is being developed to a specification, but the review is just as important when an item is off-the-shelf or built to a previous design.

In developmental products, it is imperative that relevant product stakeholders are involved in requirements generation and flowdown to ensure the product will perform as intended in the user's environment. Accurately expressed requirements that are clearly communicated to both internal and external suppliers will mitigate costly rework. The use of "to be determined" (TBD) and "to be revised" (TBR) values are discouraged because they can lead to confusion and problems in flowdown. Where specifications cannot avoid the use of TBD and TBR values, "work off" dates must be established. Plan for verification during the requirements writing stage at each level to ensure that requirements at all levels can be verified with confidence. Ensure you have the right internal team ownership, as appropriate: Program Management, Engineering (Systems, Design, Software, Specialty, Parts Materials and Processes (PMP), Manufacturing, etc.), Quality Assurance, Finance, Subcontract Management, Mission Assurance, Safety, Planning, Security, Configuration & Data Management, Contracts, Test, Environmental Safety & Health, Property Management, etc. These functions are typically involved early in the subcontracting process and before the PDR phase. Assess the overall maturity level of the requirements set with the supplier, providing programs with:

- Rigorous examination of technical and contractual requirements
- Gaining objective consensus on requirements with suppliers
- Surfacing areas of concern, risk, margin, cost drivers, and opportunities

- Keeping technology maturity progress visible via Technology Readiness Level (TRL)
- Developing and driving specific time-phased closure plans
- Review of all custom parts being fabricated by suppliers to determine any product-specific quality provisions or additional flowdown requirements

In both build-to-print and development subcontracts, the supplier and prime need to focus on challenging assumptions of similarity in process, materials, personnel, materials, facilities layout, environment of laboratory or manufacturer assumptions. Very few items are built from a clean sheet, and the validity of similarity or heritage needs to be questioned to help identify areas of change so that effects of the change can be managed.

Even with the thorough review of requirements with suppliers, there are still risks and barriers in the flowdown process. Manage the supplier requirements risks as part of the program business rhythm. Be proactive with the suppliers to prevent the risks from becoming realities.

9. Recommendations for Reducing Technical and Quality Risk

The following recommendations are the result of the collective experience of the MAIW team members and the panel members the team interviewed. This is not an exhaustive list, but these are the ones that came up repeatedly in discussions of supplier risk. Each of these recommendations is essentially based on a lesson(s) that has been learned the hard way. Details of the incidents are not included in order to preserve prime-supplier relationships and to avoid inadvertent inclusion of proprietary details. Numerous specifications and standards are in place for processes and functions of a space vehicle. The following recommendations attempt to focus the supplier management team's attention on the nuances that have repeatedly caused issues in subcontracts.

9.1 Recommendation 1: Engineering oversight role, skills and knowledge, and business acumen should be well defined

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☐ Supplier Program Manager (SPM) ☐ Supplier Quality (SQ)
☒ Engineering Technical Lead ☐ Subcontract Lead

NOTES: Most critical in Build-to-Spec and New Product

RECOMMENDATION HIGHLIGHT

The engineering oversight role should not be combined with the project management role. This can often lead to inadequate emphasis on core engineering and technology issues. Be sure to use the prime's experts, particularly if the prime has in-house capability similar to the supplier.

Be sure that the prime contractor's engineering oversight resource is aware of the sub-tier subcontract scenarios to ensure that adequate engineering oversight is being applied.

The knowledge, skills, and know-how of the prime contractor's supplier management team (SMT) and integrated product team (IPT) are critical to flushing out any probable technical risks prior to getting into a contractual relationship with the supplier. Involve the customer if the expertise is available.

RATIONALE FOR RECOMMENDATION

It is essential that the interfaces and abilities of the customer are well understood, that the skills of the technical team are at a level to understand and uncover technical escapes, and that the role is not superseded by other tasks.

DISCUSSION OF RECOMMENDATION

The purpose of engineering oversight is to have the ability for the prime to reduce or eliminate the engineering or technical escapes or omissions as early as possible in the design life cycle, and to ensure design integrity and robustness while maintaining efficiency. The objective is to provide a process that uncovers undiscovered or unidentified design risks at the supplier so these design risks can be mitigated or the cause corrected as early in the design cycle as possible. Engineering is responsible for monitoring the supplier technical development progress, status, and issues. This is accomplished through oversight. Late discovered technical issues or escapes can risk mission success.

9.2 Recommendation 2: Watch for change to supplier critical personnel

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf
☒ Build-to-Spec/Off-the-Shelf
☒ Build-to-Print/New Product
☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM)
☒ Engineering Technical Lead
☒ Supplier Quality (SQ)
☐ Subcontract Lead

NOTES:

RECOMMENDATION HIGHLIGHT

Supplier capabilities change, particularly with changes in staffing and critical employees. Ensure that a plan exists with the supplier concerning the critical personnel at the supplier. What happens if they leave? Can the supplier still produce a product that meets the requirements of the contract?

RATIONALE FOR RECOMMENDATION

A change in critical personnel can quickly change the supplier's capability.

DISCUSSION OF RECOMMENDATION

Understanding the change to the capabilities of the supplier will determine the level of resources required to manage the activities at the supplier. Changes to management of all supplier related technical activity performed to support a program will determine the level of oversight by the technical representative. The ability of a supplier to manage cost and schedule, and perform the technical engineering necessary for the product should be evaluated prior to program initiation when significant changes to key personnel occur or are about to occur.

Software is sensitive to programmers who personalize their code with minimum comments and optimized comments and optimized algorithms. Adherence to agreed-upon software standards, practices, and processes is crucial in avoiding these development traps. But even with consistent approach to standards, software still carries a close relationship with the code owner who understands the little idiosyncrasies that can only be learned by experience. A long-term pact that the key software designers will be available during system testing is always strongly desired, if not mandatory. The loss of a key programmer may be catastrophic to the program.

Loss of key technicians on the production line can devastate production if processes are not well understood, controlled, and documented. The nuances of manufacturing and assembly processes are difficult to fully document. Pay attention to how the supplier is reducing risk by cross training, mentoring, and documenting tacit knowledge. When key technicians change or when new, relatively inexperienced technicians are introduced into manufacturing, keep an eye on quality indicators to catch issues as quickly as possible. Personnel changes can result in the supplier losing the recipe for their product.

Change in key personnel is just one of the seemingly insignificant events that can have dramatic effects on assumptions of product similarity.

9.3 Recommendation 3: Qualification by similarity must be demonstrated by the data

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf
☒ Build-to-Spec/Off-the-Shelf
☒ Build-to-Print/New Product
☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM)
☒ Engineering Technical Lead
☒ Supplier Quality (SQ)
☐ Subcontract Lead

NOTES: All roles share a responsibility for verifying that similarity is supported by the data, but the supplier program Leader has the ultimate responsibility.

RECOMMENDATION HIGHLIGHT

During the proposal phase, appraise where requirements are anticipated to be met through similarity(s), where they are to be addressed (prime, supplier), when they will be addressed, the impact they may have during production, program impact risks associated with each, and what data is needed for properly addressing and documenting these efforts.

It is imperative that the right personnel are assessing pre-award similarities and the assumptions being made in order to properly evaluate and determine the correct path forward.

RATIONALE FOR RECOMMENDATION

Although the requirements may have been met on previous programs, factors such as processes, personnel, materials, etc., may have changed or may change during the life of the program that could have a major impact on the current program production. The application must be similar in launch platform, orbit and mission life. Failure to confirm similarity early and continually re-confirm may have unforeseen and disastrous effects on the final product, program schedule, and/or cost.

DISCUSSION OF RECOMMENDATION

Assumptions of similarity can be invalidated by a number of factors. Material changes may lead to process changes that lead to testing changes, etc. These changes may totally invalidate the program's prior "meeting requirements through similarity" position and may have a domino effect on other requirements.

Most space system designers assume a great deal of similarity and work to limit the number of non-heritage items on a vehicle. Look for changes in interface requirements, environmental requirements, manufacturers, manufacturing process, location, environment, or workforce, and as differences are identified, consider the deleterious effect the changes may have on the product. Any change must be evaluated and the effects and results documented. Changes may dictate mandatory modifications to SOWs, test plans, specifications, data item descriptions (DIDs), etc., or may lead to additional tests to confirm that similarity is still a valid assumption.

Additionally, assumptions of similarity made during the proposal phase should be carried as risks until the assumptions are confirmed or corrected. Although similarity evaluation/assumptions commence during the proposal phase, they must continually be revisited during the complete program schedule timeline to capture any negative impact they may have as early as possible in the life of the total program schedule.

Have boundaries of similarities been defined by the buyer? What is the age of the data used for the qualification by similarity? The buyer must evaluate and agree on a similarity risk position prior to award. What are the acceptable parameters (5 years or 6 years) for the age of qualification data? Optimally, the similarity data will be evaluated as part of the proposal,

Avoid awarding a subcontract and then discussing these questions. The buyer will end up paying for the discussions and if the similarity is rejected then the buyer will pay for the original requirement performed.

9.4 Recommendation 4: Reviews must be driven by technical readiness and gates rather than calendar milestones

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☐ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM) ☒ Supplier Quality (SQ)
☒ Engineering Technical Lead ☐ Subcontract Lead

NOTES: All roles share the responsibility depending on the requirements for the review and where the review is taking place.

RECOMMENDATION HIGHLIGHT

Occurrence of gated milestones (e.g., Technical Kick-off Meetings (TKM), System Readiness Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR), Manufacturing Readiness Review (MRR)) must be based on achieved design review entrance and exit criteria. The entrance and exit criteria should not be simplified in order to allow the review to happen if the program is not technically ready.

RATIONALE FOR RECOMMENDATION

Program reviews should not be driven by a calendar date. Program milestone schedules should be driven by the program's technical readiness for the review. Taking liens on technical requirements that are not complete prior to or during the review only increases risks on the program and pushes them further down the schedule rather than minimizing then.

More focus must be placed on whether technical and quality requirements are being met and minimize the pressure to hold the review on a predetermined date. Allowing a supplier to proceed on technical requirements that are not met only increases risk on the program rather than minimizing it.

DISCUSSION OF RECOMMENDATION

Program review milestones entrance and exit criteria must be mutually agreed upon by the prime and supplier during (or prior to) the program kick-off meeting. The program must establish gated events that are technically driven by technical entrance and exit criteria. Technical requirements must be met prior to the review being performed.

This allows for discovering and preventing and correcting engineering process errors, assists in determining how much engineering oversight is needed, increases the fidelity and accuracy of the review and provides early insight into production risk associated with design change, systems requirements, and bill of materials.

Also, ensure the right personnel are assessing the technical requirements, and entrance and exit criteria and performing the review. If the technical review requires assessment by a systems engineer, then make sure the technical reviewer performing the assessment is a systems engineer. If the required technical knowledge does not exist internally, consider outsourced consultants whose credentials, expertise, and relevance can be verified. If the internal support has conflicting responsibilities, consider rescheduling the review or having the material reviewed in advance.

If all the gated events requirements are not met, it is imperative that a lien or action item is used to capture the discrepancy and that the issue is tracked to closure. Design reviews are held to ensure the design is at the proper level of maturity and that the design closes. Following up on issues ensures that the product sell-off will go smoothly at the end of the program. It is in the best interest of the customer, the prime, and the supplier to capture the issues and get them resolved as early as possible in the program.

9.5 Recommendation 5: Maintaining domain technical knowledge

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf
☒ Build-to-Spec/Off-the-Shelf
☒ Build-to-Print/New Product
☒ Build-to-Spec/New Product

Primary Responsibility:

☐ Supplier Program Manager (SPM)
☒ Engineering Technical Lead
☐ Supplier Quality (SQ)
☐ Subcontract Lead

NOTES: Shared between the Engineering technical lead and the Manufacturing leader.

RECOMMENDATION HIGHLIGHT

Maintaining domain knowledge with respect to the requirements flowdown becomes a challenge as the design work is outsourced. The people involved in requirements flowdown and verification need to have enough domain expertise to be able to understand the implications of requirements changes.

RATIONALE FOR RECOMMENDATION

As increasingly more design work is being outsourced, it is imperative that enough expertise and experience is retained in-house to generate and evaluate requirements that are flowed to suppliers.

DISCUSSION OF RECOMMENDATION

There is no substitute for hands-on experience. Partial in-house builds (smaller or less complex) or laboratory research efforts are two ways to maintain an in-house capability. It is critical that the requirements review and the peer review are done with a person that has sufficient domain knowledge to accomplish a competent review. Use both seasoned and working-level designers to get views from both the active designers and those with long-term experience. If competent personnel are not available internally, consider independent consultants whose credentials, expertise, and relevance can be verified. A request for government resources such as Federally Funded Research and Development Center (FFRDC) support may be considered. The prime's quality field staff may be the corporate memory for the supplier and sub-tier supplier, and should also be considered as a resource.

9.6 Recommendation 6: Address known historical failure modes

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☐ Supplier Program Manager (SPM) ☐ Supplier Quality (SQ)
☒ Engineering Technical Lead ☒ Subcontract Lead

NOTES: Shared between the Engineering technical lead and Subcontracts (purchasing) lead.

RECOMMENDATION HIGHLIGHT

As a counter-measure to address known historical failure modes identified during numerous root cause analyses over the past few years, conduct informal working meetings to address lessons learned. Lessons learned should be captured in command media or other appropriate knowledge capture environment.

RATIONALE FOR RECOMMENDATION

Formal reviews have not been flushing out enough risk. An informal, working-level environment with the supplier allows for candid discussion about all potential risk areas.

DISCUSSION OF RECOMMENDATION

I. The supplier may be hesitant to share as openly in formal reviews. Use informal reviews to ensure lessons learned are captured and risks mitigated. The working-level nature of this meeting allows it to be more of a content-driven, constructive conversation as opposed to a checklist-driven meeting.

II. Examples include:

   a. Tooling and setup: Tribal knowledge that was resident in the legacy team was not present in the incoming team. Discovery of the knowledge gap allows the team to work the lack of knowledge and experience to increase the probability of success.

   b. Identification of equipment that has been replaced due to wear-out so that the equipment can receive the additional check-out required to ensure product integrity

   c. Process automation

   d. Product and part obsolescence

9.7 Recommendation 7: Technical requirements flowdown is crucial to the success of the program and must begin with a technical kick-off meeting

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf
☒ Build-to-Spec/Off-the-Shelf
☒ Build-to-Print/New Product
☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM)
☒ Engineering Technical Lead
☐ Supplier Quality (SQ)
☒ Subcontract Lead

NOTES:

RECOMMENDATION HIGHLIGHT

Requirements flowdowns are crucial to the success of a program. The optimal way to establish a supplier contract is with requirements that are complete, accurate, unambiguous, verifiable, and traceable to the requirement sources. We must also ensure that suppliers completely understand the technical requirements, that the supplier chosen can satisfy the requirements, that the requirements are technically feasible, and that the supplier has demonstrated domain expertise. The technical requirements, including quality and mission assurance, should also be clear and agreed upon at the outset of the contract.

RATIONALE FOR RECOMMENDATION

Despite the many lessons learned and expansive check-lists, gaps continue to appear. Careful attention to the maturity and thoroughness of technical requirements flowdown are key to risk identification and mitigation of any negative effects.

DISCUSSION OF RECOMMENDATION

I. It is imperative that the right team is assembled to generate the technical requirements flowdowns. Ensure you have the right internal team ownership, as appropriate: Program Management, Engineering (Systems, Design, Software, Specialty, Parts Materials & Processes, Manufacturing, etc.), Quality Assurance, Finance, Subcontract Management, Mission Assurance, Safety, Planning, Security, Configuration & Data Management, Contracts, Test, Environmental Safety & Health, Property Management, etc. All stakeholders should keep an overall system engineering perspective to ensure requirements are cohesive and to assess the overall maturity level of the requirements set with the supplier.

II. Requirements must be thorough and stable at the beginning of the program. Do not assume the supplier understands the technical requirements even if you are 100% confident they have been communicated in the technical specifications. Have a face-to-face (see technical kick-off process below) with the supplier technical team, if possible, and ensure the requirements are mapped prior to going on subcontract Also, do not assume off-the-shelf items meet your requirements just because your specification is within the supplier's specification range.

   a. The technical kick-off process is an accelerated, structured process for identifying risk early in the program/subcontract lifecycle. Using a structured process and a collaborative environment, the technical kick-off process provides the ability to:

      1. Pull technical risk further forward in the design process
      2. Surface potential failure modes for critical technical parameters
      3. Capture a quantifiable technical risk baseline
      4. Feed the program's risk management process

5. Reinforce multi-functional acknowledgment, concurrence, and accountability of technical risk
6. Further integrate the team (supplier management team or integrated product team) and increase understanding of mutual objectives.

III. Even with maturity of requirements being solidified at the beginning of the program, there are often changes that occur throughout the life of the project. The flowdown of requirements should also include as much advance notification of engineering changes as early as possible (e.g., engineering specifications, materials, processes specifications) as well as changes to supplemental requirements (e.g., inspection, testing, shipping, handling, packaging issues). The lack of requirements maturity and unknown changes increase the risk of noncompliant and nonconforming product. This situation requires more Engineering Assurance oversight. Indicators include:

   a. Data Timeliness: Suppliers are given drawings and specifications needed to build hardware. However, the process to ensure suppliers get revisions to drawings and specifications in a timely manner is inconsistent. Requirements are not delivered as scheduled and late requirements in turn feed incomplete designs.

   b. Requirements Maturity: “to be revised” and “to be determined” are still included in requirements documents beyond the agreed upon schedule. Communication of requirements between the prime organization and supplier are not consistently or adequately managed to allow feedback within the constraints of the detailed program schedule.

   c. Schedule Lag in Decisions and Reviews: Suppliers are given design products (e.g., drawings and specifications needed to build hardware) but design data contractually requested as part of the deliverable are received but not reviewed in a timely manner. Issues found in supplier data occur much later than acceptable due to lag in review of product data compared to product acceptance. Requirements affecting suppliers who design and manufacture Build-to-Specification hardware are flowed but not in a consistent and timely fashion.

IV. Use concise documentation to flow pertinent requirements to the supplier. Do not overload or confuse the supplier and engineering oversight by delivering requirements in numerous documents, each containing just a few of the requirements.

9.8 Recommendation 8: Protect your program from anomalies that occur after product delivery

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM) ☒ Supplier Quality (SQ)
☒ Engineering Technical Lead ☒ Subcontract Lead

NOTES:

RECOMMENDATION HIGHLIGHT

Latent issues and/or the threat of latent issues may be discovered after the unit is delivered, installed, and even launched.

RATIONALE FOR RECOMMENDATION

Latent issues are just that – the best defense is to not have any; the next best defense is to have sufficient data available to determine your risk and path forward, should a latent issue be identified.

DISCUSSION OF RECOMMENDATION

These issues may become identified through a Government Industry Data Exchange Program (GIDEP), the Space Quality Improvement Council (SQIC)/GIDEP National Security Space Advisory Forum (NSSAF), one of the government systems for Parts, Units, Materials, Processes and Subassemblies (PUMPS) or other industry alert, a failure or anomaly with your device or material, or a good faith notification from your supplier that they had experienced an anomaly or failure that might have reach back or reach across implications for you. The buyer must ensure the supplier is aware of any GIDEP or other industry alerts. Don't assume they subscribe to these services.

A thorough knowledge of the device or material in question is paramount in determining a quick and efficient assessment of the anomaly or potential anomaly. Information you would want at your "immediate" disposal includes:

1. Qualification history for the device
2. Application-related tests performed to validate its use –
    a. Are there gaps in the planned versus actual platform used?
3. MRB decisions for this device or material
4. A complete as-built-configuration pedigree with part and material numbers, suppliers, and lot date codes for all material used
    a. Associated field and receiving inspection records
    b. Additional test records such as Destructive Physical Analysis (DPA) and radiation.

Suggestions for keeping abreast of issues that may affect you after product delivery –

1. Utilize the GIDEP system
2. Encourage your suppliers to use the GIDEP system
3. Investigate establishing agreements with your suppliers to alert you of adverse information they discover after product delivery.
4. Participate in available Government/Industry forums such as the SQIC, MAIW, Lessons Learned Workshop, and Space Parts Working Group.

9.9 Recommendation 9: Use engineering oversight to gain insight into supplier and sub-tier capabilities and performance

Applicable Supplier Segment:

☐ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☐ Supplier Program Manager (SPM) ☒ Supplier Quality (SQ)
☒ Engineering Technical Lead ☒ Subcontract Lead

NOTES:

RECOMMENDATION HIGHLIGHT

Established product baselines that relate to product performance and qualification are vulnerable to unidentified process changes incorporated by sub-tier suppliers.

RATIONALE FOR RECOMMENDATION

While sub-tier management is a cornerstone of most pre-award surveys and change notification is a standard purchase order clause, unidentified process and material changes still find their way into established product baselines. Understanding how these escapes may happen will help define a robust risk mitigation plan.

DISCUSSION OF RECOMMENDATION

The complexity and/or cost of the hardware or related processes often dictate the resources applied to ensure their integrity. Simply put, a quick, simple, or inexpensive process or material does not garner the same attention as its expensive counterparts. Here are some practical examples of areas that may be overlooked:

1. An absolute reliance on a legacy sub-tier supplier without periodic revalidation of the product or process that earned them your trust.
    a. When was the last time the product was produced and what was the outcome?
    b. When was the last time this sub-tier supplier revalidated the delivered item or process?
    c. Does the sub-tier supplier have the exact same processes, facilities, employees, and sub-tiers that provided the originally qualified product?
2. Some risk areas to consider
    a. Is the sub-tier using the same plating baths that were qualified? Many plating shops and component suppliers have gone to lead-free tin plating (referred to as Restriction of Hazardous Substances or RoHS) and do not notify anyone, thinking that plating is plating. Tin plating without 3 to 6% lead is susceptible to growing whiskers that can result in electronics shorts or electrical arc, both of which can have devastating effects on the product performance.
    b. Does the sub-tier perform prohibited material testing on all appropriate purchased material and components?
    c. Has the material gone through thermal processing in accordance with the thermal processing procedure? This could be an issue with castings and forging.
    d. Are special processes for electrical, electromagnetic, electromechanical, and electro-optical (EEEE) parts robust and proven?
        i. Solder coating of gold leads?
        ii. Package and part integrity after lead forming, vapor phase installation, etc.?

iii. Established Electro Static Discharge (ESD) practices during retesting or screening?

iv. Correct programming and identification of Programmable Read Only Memories (PROMs), Electrically Erasable Programmable Read Only Memories (EEPROMs), and Field Programmable Gate Arrays (FPGAs)?

3. Risk mitigation techniques

   a. X-Ray Fluorescence (XRF) testing for prohibited materials for all purchased material

   b. Batch- or lot-related plating thickness and integrity testing

   c. Evidence of process qualification where testing is not feasible

9.10 Recommendation 10: Perform supplier quality system verification and assessment

Applicable Supplier Segment:

☐ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☐ Supplier Program Manager (SPM) ☒ Supplier Quality (SQ)
☐ Engineering Technical Lead ☐ Subcontract Lead

NOTES: The recommended primary responsibility is with the supplier quality representative. However, the entire team should be aware of any issues or risks identified by the supplier quality team and the status of the supplier's quality system.

RECOMMENDATION HIGHLIGHT

Perform periodic supplier quality system evaluations and assessments or audits that are applicable to a supplier's facility and/or business. The quality and product assurance requirements that the prime wants the supplier to follow should be captured in the subcontract. Quality assurance (QA) and product assurance (PA) requirements that are contractually mandated can be audited by the prime. The frequency of QA and PA audits for a product may depend on performance. Supplier quality system evaluation or assessments should be part of periodic supplier maintenance. A change in supplier status should prompt a re-evaluation of the supplier and the supplier oversight approach.

The supplier should be assessed for compliance to quality assurance requirements included in the subcontract. This is accomplished through the performance of capability reviews, quality system assessments, source/receiving inspection, and supplier quality surveillance activities. Nonconformance data collected from inspections at the suppliers and in-house should be examined in a Corrective Action Board (CAB). The CAB would make adjustments to the amount and type of surveillance based on the severity of the issues and the trends. This feedback should be incorporated into the prime's supplier database for use on other programs with that prime.

RATIONALE FOR RECOMMENDATION

Reviewing suppliers early in the procurement for capability and quality system effectiveness will direct changes in the monitoring of the supplier that are intended to mitigate risks. For example, if a supplier's data exhibited numerous solder nonconformances, additional activities in the form of verification of completed root cause/corrective action, added inspections, or surveillance would be applied to reduce/eliminate the issue.

DISCUSSION OF RECOMMENDATION

The approach to ensuring the sustainment of a supplier's quality system can be accomplished in three stages: (1) capability review, (2) quality system initial evaluation and maintenance, and (3) Supplier quality surveillance activities.

1) The capability review is performed prior to contract award by a multi-discipline team that assesses the supplier's performance. It is a detailed on-site examination of a supplier's manufacturing and support processes and controls used during the design, fabrication, assembly, and testing of hardware and software. The review examines factory controls, production readiness, assembly and test, quality processes, planning controls, configuration management, inventory controls, training, supplier quality, subcontract management, materials and processes, and control of special processes.

2) The initial quality system survey can be accomplished by an on-site verification to an established standard (e.g., AS9100) or can be gained by utilizing third-party registration. Make sure you have the right product and manufacturing experts with the team when they evaluate the supplier's manufacturing line. Look for controls and how they are managed. After the initial establishment of the quality system, regular substantiations are established to ensure the maintenance of the system.

3) Supplier Quality Surveillance (SQS) is a combination of targeted activities based on the risks of doing business with the supplier. The risk is determined by a number of factors such as past performance, corrective action requests, system deficiencies, and customer complaints, etc. SQS takes three formats: Quality Process Assessment (QPA), Manufacturing Process Assessment (MPA), and a product audit. An example of a QPA would be an assessment of the supplier's ability to review the requirements outlined in their purchase contracts. An MPA would assess the capability of their supplier's soldering process. The product audit takes a specific product and reviews the whole manufacturing cycle.

9.11 Recommendation 11: Question and confirm assumptions of similarity in materials and manufacturing processes

Applicable Supplier Segment:

☐ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☐ Supplier Program Manager (SPM) ☒ Supplier Quality (SQ)
☒ Engineering Technical Lead ☐ Subcontract Lead

NOTES:

RECOMMENDATION HIGHLIGHT

During the MRR and the manufacturing phase, be alert to changes in materials, personnel, manufacturing process, facilities, financial health of the supplier, business mergers, and other items that may invalidate the assumption of heritage or similarity or affect the consistency of manufacturing procedures and quality standards.

RATIONALE FOR RECOMMENDATION

Despite the many lessons learned and expansive checklists, gaps continue to appear. Careful attention to ALL change is the key to risk identification and mitigation of negative effects.

DISCUSSION OF RECOMMENDATION

The level of detail examined during a general practice MRR is often at a higher level than where, and by whom, the work is actually being performed. Seemingly unrelated changes may affect the manufacturing consistency and quality. The following examples are not an exhaustive list, but are some areas that have been identified in the past.

1. Facility changes: Changing anything about the manufacturing environment has the potential to affect the quality of the product. These changes can be as simple as an upgraded environmental control system, changes in floor wax, or drastic changes such as moving to a new facility. These changes require re-validation of process and environmental control.
2. Business mergers and financial health of the supplier: Dramatic change of management or financial crisis may result in “optimization” of process and quality control as a cost-saving measure without clearly understanding the unintended consequences.
3. Changes to manufacturing processes and materials: Upgrades and changes to manufacturing processes are inevitable, but during the changes and upgrades, recharacterization and revalidation of the process control is necessary. Cutting corners in this area may seem financially prudent at the time to the specific vendor, but could have disastrous results on the larger program. Also consider that multiple small changes, while they may each be acceptable, may cause an unintended drift in the product quality or function. Consider periodic re-qualification of the design to ensure it is still functioning as intended. This is already mandatory for EEEE parts in the form of Quality Conformance Inspection (QCI).
4. Review supplier capability: Capability of the supplier also needs to be carefully reviewed. This review process must include the proper granularity of information needed to assess a supplier’s technical capability under the circumstances of your specific product. A clarifying example would be where a machining organization on the approved suppliers list may not be capable of producing all machining to the required tolerance and geometric complexity level needed. The capability of the supplier must be evaluated against the degree of difficulty of the task.

The people at the worker level are in touch with manufacturing equipment and processes and are more likely to be able to identify changes in equipment, people, materials and manufacturing processes, and quality processes. Question the people involved in doing the actual work as part of the MRR process. Solicit the worker-level input for the formal risk matrix that will be shown at the MRR. Also refer to Appendix B for a detailed checklist for performing an MRR.

9.12 Recommendation 12: Sell-off will go more smoothly if data is continually managed during the program and issues are worked as they are uncovered

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print /Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec /Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM) ☒ Supplier Quality (SQ)
☒ Engineering Technical Lead ☐ Subcontract Lead

NOTES: The recommended primary responsibility is Supplier Program Leader to set the tone and relationship for the interactions. Engineering and Quality will follow up on all the details leading up to sell-off.

RECOMMENDATION HIGHLIGHT

Product close-out and sell-off is the last chance for the prime to resolve outstanding product issues and prevent defects from being passed on to the system. The sell-off should be a summary-level meeting. There should not be any new issues, and the hardware acceptance documentation should be complete and available for review.

RATIONALE FOR RECOMMENDATION

During the subcontract close-out and sell-off of the unit, the prime reviews the records associated with the product for adequacy. This review can be accomplished as a rolling sell-off during the verification portion of the program with a summary at sell-off, or be a comprehensive review of the entire sell-off package. The depth of review should be tailored depending on the liberties given to the supplier during the acquisition.

If issues arise with the product during the development and production, the issues should be shared and worked with the customer as soon as feasible. Non-compliances and issues are more easily handled across a program when they are identified early. Non-compliances and delegations associated with disposition based on the severity level of these nonconformances may require prime approval to ensure sound decision making is taking place.

The complete product pedigree is typically required in order for the customer to accept the hardware. In order to avoid costly re-testing or re-collection of data, the supplier program leader should ensure that a data management system is established at the outset of the program to collect the documentation as it is created and signed off.

DISCUSSION OF RECOMMENDATION

Expectations for the sell-off review should be established well in advance of the event. Keeping the expectations for the event high will help make the sell-off uneventful and thorough.

The requirements of the subcontract should be reconciled with the contract deliverables prior to sell-off to ensure that the current design, design documentation, and testing procedures were sufficient to ensure the unit will perform as intended in the system. Discrepancies must be noted and corrected prior to final sell-off. Deviations and waivers should have been evaluated in advance to make sure that the unit still meets system requirements. If new problems are brought up at sell-off, there typically is not time to do anything to resolve the issues without impacting the larger program schedule.

The supplier should make the following records available for review in advance of the event with sufficient time for the prime to perform an adequate review:

- Requirements verification ledger for the unit
- Material Review Board (MRB) actions, waivers and deviations

- Manufacturing documentation
  - Unit build history
  - Manufacturing Instructions and processes
  - Complete build inspection and as-tested report signed by the supplier responsible engineer and supplier QA
- Test Summary that includes the following:
  - Test review boards actions and summary
  - Failure review board actions and summary
  - Test anomalies and resolution summary
  - Resolution of unverified failures
  - Out of family test results
  - Description of environmental exposure, operating time, and number of cycles
  - Identification of all associated test equipment, test software, and test calibration results
- Parts, Materials and Process Summary
  - Parts, Materials, and Processes Control Board (PMPCB) Summary
  - Description of any parts problem encountered
  - Approved parts list
  - As-built parts list
  - Applicability of outstanding alerts from GIDEP and government forums
- Configuration
  - Status to include a summary of all deviations and waivers
  - Unit as-built configuration description and status accounting of the as-designed versus as-built configuration at delivery
- Disposition status of all actions generated at design reviews
- Any other report required via the SDRL section of the pertinent SOW
- Integration of lessons learned from previous units
- Complete unit history to include: storage history, installation dates, removal dates, reason for removal, references to discrepancies or failures, references to inspections, rework, repair and retest
- Delivery plans
  - Readiness of receiving organization
  - Handling fixtures and procedures
  - Integration processes
  - Transportation arrangements
  - Hardware packaging
- Product closeout photos may also be required

The supplier may supplement the above items with additional items needed for a complete, accurate, acceptable, auditable, and successful review. The supplier should make all supporting documentation for these summaries available for examination in advance of the event for careful review and during the sell-off, including complete verification records, material and parts traceability to include lot date codes, and manufacturing details. The sell-off package from one program is likely to be used as the justification for assuming heritage on a future program. A complete hardware acceptance package can help reduce risk for the current and future programs.

9.13 Recommendation 13: When writing requirements, plan for verification and treat the verification and validation as risk mitigation

Applicable Supplier Segment:

☒ Standard Parts and Commodities ☒ Purchased Technologies ☒ Directed Purchase ☒ Strategic Alliance

Subcontract Product Classification Quadrant:

☒ Build-to-Print/Off-the-Shelf ☒ Build-to-Print/New Product
☒ Build-to-Spec/Off-the-Shelf ☒ Build-to-Spec/New Product

Primary Responsibility:

☒ Supplier Program Manager (SPM) ☐ Supplier Quality (SQ)
☒ Engineering Technical Lead ☐ Subcontract Lead

NOTES: The supplier program leader is primarily responsible for setting the expectations for the requirements and verification to be complementary activities. Engineering needs to make sure the technical performance is being demonstrated incrementally.

RECOMMENDATION HIGHLIGHT

Set the expectation for verification and validation early in the program. Make sure the CONOPS is considered in the planning and use the CONOPS to apply the Test-Like-You-Fly philosophy to the unit. Incrementally build up the verification program to increase confidence in the product and interfaces as it matures.

RATIONALE FOR RECOMMENDATION

There are multiple reasons why verification and validation fail and this recommendation serves to help prevent many of the pitfalls.

DISCUSSION OF RECOMMENDATION

The requirements flowdown and requirements verification are complementary. Requirements must be written in such a way that they fully define the performance required and can be verified. There are many reasons why verification and validation fail and the following lists six common reasons for failure and recommended mitigation:

1. Reason for V&V Failure: Requirements may lack stability and may contain TBD/TBRs until late in the design process.

   Late agreement on requirements definition and the process to verify have large program impacts. Next level of assembly, program, and customer agreement has to be obtained early to agree on process, plan, data, performance, function, operation, configuration, and environment. Programs with long (3+ years) development cycles have the potential for program and customer turn-over making accurate and clear documentation of agreements even more important. Continuous education and monitoring of future tasks with clear documentation (contractual, programmatic, and technical) is needed to ensure program will progress along an agreed-to plan.

2. Reason for V&V Failure: Inaccurate requirements

   Equally egregious as floating requirements are inaccurate requirements. If the technical budgets have errors or are incomplete, then the test plan and resulting verification will be flawed. Requirements stability early in the program is highly desirable, but accuracy is more important than timeliness.

3. Reason for V&V Failure: Limitation on duplicating the space environment

   The Test-Like-You-Fly approach attempts to recreate the operational environment as closely as possible during test. It is important to understand the normal operations and non-normal operation sequences when creating Test-Like-You-Fly plans. Sequence can play a big part in boundary checking and overall verification effectiveness. Many examples exist to emphasize the importance of adhering to this tenant. Despite the most noble efforts, some aspects of the space environment cannot be duplicated on earth, such as effects of zero gravity. Combined effects of various environmental factors may be beyond the available testing capabilities. The result is a risk that the

system may not operate as intended once it is on orbit.

4. Reason for V&V Failure: Verification does not address simultaneous operations that will be encountered during operation

   The CONOPS is invaluable in ensuring the Test-Like-You-Fly approach. Where perceptible V&V is possible in the development and AI&T process at a lower level, documented demonstration should be performed to ensure that high-level assembly demonstration of Day-In-The-Life and key operations can be performed simultaneously. These demonstrations and validation not only ensure operations, but ensure agreed-to expectations and education to the next higher level.

5. Reason for V&V Failure: Imperceptive testing and lack of pedigree documentation

   Use perceptive AI&T that is well documented to mitigate future risks and to help in debugging present issues. Higher levels of assembly rely on lower operations and tests that, if there is an issue, have large impacts without key information.

6. Reason for V&V Failure: Different interpretations of interface documents

   Subtle differences in definitions of interfaces without early V&V can be catastrophic to programs. Not only are clear definitions and perceptive V&V required, but higher levels of assembly should understand the high-probability risk areas within the interface composition and determine mitigations and/or workarounds. A provision in the subcontract for early delivery of a unit-level interface simulator is recommended. The interface simulator can mitigate the risk of mechanical, electrical, and software interface incompatibilities within the system.

10. Conclusion

Technical and quality issues will continue to occur at suppliers. History has shown that even with the best engineering focus on suppliers, product problems occur. The space industry prime contractors, suppliers, national agencies, and government must continue to have the supplier management function as a core competency. It is estimated that approximately 80 percent of the cost of purchased material, services, and product equipment is designed in before the purchasing activities begin. It is equally important to control the technical complexity and product design to assist with minimizing the technical and quality risk and control. Additionally, many of the manual tasks that the procurement team uses to perform transactions have now been automated, and most prime contractors are either currently working in a paperless system or soon will be. Prime contractors are moving to electronic-commerce systems to manage transactions between companies. The prime contractors have also added other functions to the supplier IPT such as supplier quality, technical leads, and supplier program managers, plus others that were not included in this document. The role of managing suppliers has gotten more complex in the past 20 years and will continue to challenge organizations.

Several supply chain models were illustrated early in this document to provide tools to assess the supply base. If applied, the models will highlight areas for risk and areas that may require specific controls. Using the models could lead to changes within organizations, operations, and supplier strategies. Strategic supply chain leaders involve their teams to create a roadmap for achieving their company quality goals and risk controls. It is not always what tools are being applied but leadership. Leadership inspires world-class goals.

The writers feel that they have provided some new information for readers to apply to their business opportunities. We thank everyone who has contributed to this document and hope that it can eliminate some technical and quality issues at your suppliers.

Appendix A. Industry Panel Discussion Notes

In an effort to obtain other industry inputs for the team, industry panel discussions were conducted with the prime contractors providing senior subject matter experts. The panels were conducted on September 29, 2010 and October 27, 2010. The panel members were Vince Ciampa, Strategic Subcontract Initiatives and On Site Support, Lockheed Martin Space Systems Company; Andre Burghard, Mission Assurance Manager, Northrop Grumman Aerospace Systems (NGAS); Gabriel Bakhit, Failure Analysis, Raytheon Company Space and Airborne Systems (RSAS); Chris Caballero, Material Quality Manager, Raytheon Company Space and Airborne Systems; Mark Spiwak, WGS Program Director, The Boeing Company; and Mike Winslow, TDRS Program Payload Director, The Boeing Company. The team thanks these leaders for providing their inputs. They provided a new perspective that had not been reviewed by the team. The highlights that apply to space industry products are:

- When moving products from within the prime's manufacturing business to a supplier via a subcontract relationship, make sure the engineering drawings are complete. Experience found that many of the engineering drawings for building inside the prime did not include the tribal knowledge of the experienced prime manufacturing team. It required many engineering changes to Build-to-Print engineering to get the supplier capable of repetitive builds. It also required about 200% more prime contractor product engineering support than was originally planned.

- Depending on the complexity of the product being outsourced, the supplier may not have the management systems in place to manage complex programs. Pay attention to the lack of metrics and controls to monitor the program progress. You may also experience capacity issues if the suppliers are weak in management systems. It is easy for the supplier to over-commit and not know there is a problem until it is too late.

- The things you pay attention to are the things that get done properly.

- Use of engineering models is not always enforced. Pay attention to the requirements analysis and ensure it is done with an appropriately high level of fidelity.

- Foreign suppliers are often not open to share information. Be aware, before you issue them subcontracts, of the exceptions and what you will receive.

- Pay close attention to supplier changes. Double-check any qualification challenges and understand the impact. Have your Chief Engineer, IPT, program management, systems engineering and specialty engineering engaged with the proposed changes.

- Do not underestimate the value of an engineering model or pathfinder when working with a subcontract. It gives the supplier a chance to discover any manufacturing and testing issues before working with flight hardware.

- The technical team and SMT must read all specifications, Statements of Work, and subcontracts. "You don't know what you don't know."

- Make sure you have the right product and manufacturing experts with the team when they evaluate the supplier's manufacturing line. Look for controls and how they are managed.

- All processes change over time. All processes require constant monitoring for minor as well as major changes. Suppliers must demonstrate they have controls in place to ensure the

processes are under control. Panel member introduced the term, “Shift Happens.” This is a great concept that everyone should recognize.

- Everyone requires the supplier to have an approved materials and process list but it should also include the tools and equipment used for the manufacturing and testing as well.

- Require constant monitoring of hand-held tools and equipment.

- Be aware of and use caution of a supplier that uses dissipative gloves.

- Use caution when using heritage suppliers without some detailed reviews of their manufacturing areas and management systems.

- Challenge all qualification by similarity. The systems may have changed and same processes may not be used in building the hardware. Program offices must train their supplier management teams.

- Emphasize the use of risk management plans in the proposal phase and pre-award phase.

Appendix B. Manufacturing Readiness Review and Execution Guidelines

The MRR guidelines are intended for a real-time interview of the actual technicians and other manufacturing personnel performing the required tasks to determine their linkage to the distant post-award activities and the current manufacturing requirements. The MRR guidelines help identify the recovery plans and resources available, or the lack thereof, prior to the manufacturing. This early identification of gaps within the capabilities and recovery plans at the Operator levels will provide the framework to establish additional risk mitigation plans as required. Aerospace TOR-2005(8583)-3859, *Quality Assurance Requirements for Space and Launch Vehicles*, dated December 1, 2005, provides an overview of the Quality Assurance role to ensure readiness for manufacturing. Additionally, Aerospace TOR-2009(8583)-8545, *Guidelines for Space Systems Critical Gated Events*, dated May 9, 2009, provides a complete description of a traditional manufacturing readiness review, which this TOR refers to as build readiness review.

- What is the management structure with roles and responsibilities for the manufacturing areas?
  - Who is in charge for first shift?
    - Manufacturing?
    - Test?
    - Manufacturing Engineering?
    - Design Engineering?
    - QA?
  - Same for second shift, if used? Third? Weekends?
  - What is the ombudsman process to adjudicate differences between the various teams?
  - Are sufficient controls and handoff procedures in place for second, third and weekend shift operations if they are to be used?
  - Is there a defined overlap in coverage during shift handoffs?
  - Has an emergency call list been identified to communicate with all disciplines if needed?
  - Does the critical path support the delivery lead time for the program? Is there sufficient schedule margin?
  - Is there sufficient capacity in the manpower and manufacturing capability to support the schedule?

- Shop records and instructions
  - Are there any processes being performed that are new to the organization?
  - Has a Table Top Review been performed with all participants for any new process?
  - All new/critical EEEE components?
  - What precautions are in place to ensure success?

- Work travelers, drawings and specifications
  - Have the CDR package, specifications, drawings, and work procedures been released and reviewed by Manufacturing Engineering to ensure the design is producible?
  - Does the current design STILL meet the current subcontract requirements?
  - Does the current design have any variances or waivers approved by the program?

  - Travelers should indicate where out-of-sequence operations are permitted or not permitted.
  - Has QA reviewed the Mandatory Inspection Points (MIPS)?
  - What is the notification process to identify an upcoming MIP?

- Is a Government Source Inspection required?
- Is a first article inspection required? Is there a plan for the 1st article inspection?
- What is the process to remove a MIP?
- What happens if a MIP is inadvertently skipped?
- Personnel certifications and training programs
  - How are training currency and adequacy verified for all management, manufacturing, and inspection personnel?
  - How is training performed?
  - How is certification granted and tracked? What evidence exists to show the training and re-certification policies are implemented and no operations may be performed by untrained or uncertified personnel?
  - How is certification extended?
  - Is cross training implemented for critical skills to minimize single points of failure?
- Have offload environmental and electrical/mechanical test houses been identified and qualified?
- Have provisions been made for repair of critical manufacturing hardware?
- Are the traceability requirements and material retrieval systems in place?
  - Are you required to maintain material traceability through assembly and test?
  - How is this accomplished?
  - How is it maintained through rework operations?
- Parts, Materials and Processes Requirements
  - Are the requirements for parts and materials required understood?
  - Are the correct solder, flux, bonding, and conformal coat materials in place?
  - Has sufficient lead time for material acquisition been built in to accommodate screening requirements including radiation, heat treat, life testing, etc.?
  - Have sufficient attrition quantities been identified for destructive testing and manufacturing attrition?
  - Have traceability requirements (single lot date code, etc.) been established?
  - Does the product have safe (ESD, contamination, handling damage, etc.) containers identified for products for transporting between assembly, test, and integrated areas?

- Are all soldering irons and bonding machines calibrated and properly grounded?
- Are there any obsolescence issues? Is there an obsolescence plan in place?
- Have the Workmanship Criterion been captured in the manufacturing instructions?
  - Solder?
  - Conformal coat?
  - Bonding?
- What is the MRB authority?
  - Who chairs the MRB?
  - What hardware level and disposition is associated with the delegation?
- How is change control performed?
  - Are red lines allowed and/or used?
  - If red lines are used, how are they captured and configuration controlled?
  - How are as-built configuration records maintained?
  - Review any changes to the production baseline. Detail any new processes, suppliers, and tooling that have not been tested or verified with current deliveries. Is risk management warranted, are mitigations on track?
- Rework provisions: show how rework requirements will be managed through the manufacturing line/floor.
  - How is rework authorized?
  - Are controls in place to maintain material traceability?
  - Are all previous inspections and tests invalidated by the rework done?
  - Are additional environmental tests as required with this rework?
  - Did the manufacturing change invalidate the previous assumptions relative to heritage?
  - Does the qualification plan need to change?
- Does the product have safe (ESD, contamination, handling damage, etc.) containers identified for products as they are built and transported between assembly and test areas and integrated into larger assemblies?
  - Is the final shipping container in place?
- Are process monitors in place to verify manufacturing consistency?
  - What processes are in place to ensure the integrity of the manufacturing environment – air quality, humidity, facilities housekeeping, ESD certifications for benches and tools, etc.?
  - Consider safety of the personnel as it relates to hazardous materials, weight, handling consideration, heat and noise, as well as hardware safety.
  - Have the security requirements been reviewed? How are they being met – in particular DD254, special access, secured areas, and personnel clearance?

  - What is the process to control the configuration of programmed devices that might be replaced during manufacturing, such as PROM, EEPROMS, and FPGAs?
  - Did the higher-level software change as well?
  - Have these process-monitoring considerations been communicated to all user groups and to the customer?

- What is the involvement of quality engineering during manufacturing?
  - Just for MIPs?
  - Periodic surveillance and audit of program performance?