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DEPARTMENT OF DEFENSE HANDBOOK

MANUFACTURING MANAGEMENT PROGRAM GUIDE

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Distribution Statement A. Approved for public release; distribution is unlimited.

FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense (DoD).

2. The purpose of this handbook is to promote the timely development, production, modification, fielding, and sustainment of affordable and capable DoD systems by addressing manufacturing risks and issues throughout the program acquisition cycle. It is based upon practices developed by multiple, joint government/industry teams and the SAE G-23 Manufacturing Management Committee, which developed and published SAE AS6500, “Manufacturing Management Program.”

3. This handbook is intended to be used in conjunction with AS6500. This handbook provides additional explanations of the practices in AS6500, as well as guidance on contractually implementing AS6500 in DoD contracts.

4. Comments, suggestions, or questions on this document should be addressed to the Engineering Standardization Branch, AFLCMC/EZSS, Wright Patterson AFB OH 45433-7501 or emailed to ENGINEERING.STANDARDS@US.AF.MIL. Since contact information can change, the currency of this address can be verified by using the ASSIST Online database at https://assist.dla.mil.

CONTENTS

FIGURES

TABLES

1. SCOPE.

1.1 Scope. This handbook is applicable to all phases of DoD system acquisition. This handbook describes proven manufacturing management practices to promote delivery of affordable and capable weapon systems. This handbook provides standardized guidance for DoD implementation of SAE AS6500, "Manufacturing Management Program."

2. APPLICABLE DOCUMENTS.

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

2.2 Government Documents

2.2.1 Specifications, standards, and handbooks

DOD-STD-2101	Classification of Characteristics

(Copies of this document are available online at https://assist.dla.mil.)

2.2.2 Other Government documents, drawings, and publications. The following Government documents, drawings, and publications form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE

DoD Manufacturing Technology Program	Manufacturing Readiness Level (MRL) Deskbook

(Copies of this document are available online at http://www.dodmrl.com/.)

Joint Aeronautical Commander's Group	Aviation Critical Safety Item Management Handbook

(Copies of this document are available online at https://dap.dau.mil/Pages/Default.aspx.)

UNITED STATES NAVY

NAVSEA INSTRUCTION 9078.1	Naval Ships Critical Safety Items Program, Non-Nuclear

(Copies of NAVSEA Technical Manuals can be accessed through NAVSEA's Technical Data Management site at https://mercury.tdmis.navy.mil/Default.cfm.)

NAVSO P-3687	Producibility System Guidelines

(Copies of NAVSO Technical Manuals can be accessed through https://acc.dau.mil/CommunityBrowser.aspx.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein.

IEEE 15288.2 IEEE Standard for Technical Reviews and Audits on Defense Programs

(Copies of this document are available online at http://standards.ieee.org/index.html.)

ISO 9001 Quality management systems – Requirements

(Copies of this document are available online at http://www.iso.org/iso/home.htm.)

SAE AS5553 Fraudulent/Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition

SAE AS6500 Manufacturing Management Program

SAE AS9100 Quality Management Systems - Requirements for Aviation, Space and Defense Organizations

SAE AS9102 Aerospace First Article Inspection Requirement

SAE AS9103 Aerospace Series - Quality Management Systems - Variation Management of Key Characteristics

SAE J1739 Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing, Assembly Processes (Process FMEA), and Effects Analysis for Machinery (Machinery FMEA)

(Copies of these documents are available online at http://www.sae.org/.)

3. DEFINITIONS

This handbook is intended to be used in conjunction with SAE AS6500. Refer to SAE AS6500 for manufacturing-related definitions.

4. INTRODUCTION

4.1 Purpose. The purpose of this handbook is to promote the timely development, production, and fielding of affordable and capable weapon systems by addressing manufacturing risks and issues throughout the program acquisition cycle. Its primary focus is to assist in the contractual application of SAE AS6500, “Manufacturing Management Program,” and to provide additional guidance on the implementation of best practices for manufacturing management.

4.2 Statement of the problem. In the past, the goal of developing and deploying economically supportable weapon systems capable of meeting all functional user requirements has been proven difficult to achieve. Historically, two basic problems have been experienced to varying degrees by weapon system acquisition programs: (A) difficulty in developing and producing new weapon systems, modifications, and upgrades in a timely and affordable manner; and (B) difficulty in smoothly transitioning an acquisition program from development to production and fielding supportable systems.

4.2.1 Difficulty in developing and producing new weapon systems, modifications, and upgrades in a timely and affordable manner. The difficulty in fielding mature systems in a timely and cost effective manner has been a persistent problem experienced in nearly every program. Technical and quality requirements are not adequately identified and communicated to contractors resulting in an increase in process variation and product costs. During development and production, frequent modifications to design specifications result in high initial acquisition costs. Lack of manufacturing maturity creates production schedule delays and additional engineering modifications. Late deliveries and the inability of the system to meet all requirements impact the warfighter by delaying Required Assets Availability (RAA) and reducing operational capability. Poor quality, high initial repair rates, unexpected failure modes, and numerous configuration changes impact the support community through the need for more spares, excessive failure analyses and corrective actions, more complex configuration tracking systems, and numerous technical order changes. These problems result in increased costs and potential inability to maintain adequate operational capabilities.

4.2.2 Difficulty in smoothly transitioning an acquisition program from development to production and fielding supportable systems. Most modern acquisition programs have experienced problems in transitioning from development to production. Symptoms include poor quality and low yields of key manufacturing processes, inability to support production rates using processes used in development, cost increases, and schedule delays while production capable processes are being developed. These problems can be linked to

a. lack of an effective plan for the development and maturation of production processes during pre-production acquisition phases concurrent with product development and ineffective conduct of production readiness reviews.

b. lack of understanding of the relationship between key design requirements, the processes needed to support them, and the impact on product performance, supportability, and cost.

c. ineffective risk assessment, mitigation, and monitoring activities supporting critical process development.

d. lack of clear and concise vertical and horizontal communication links throughout the supply chain. Process capability, process stability, and process controls are both quality and manufacturing management considerations and there is mutual overlap and interdependencies between the two functions.

4.2.3 Root cause. A major source of these problems is the lack of thorough consideration of the capability and stability of manufacturing processes to support production of weapon system products. This problem can be characterized with the following statements:

4.2.3.1 Inadequate response to production risk. Risk factors that pose production risk factors from the start of the program are caused by:

a. lack of understanding of existing process capabilities (process characterization).

b. limited source selection criteria related to process capability.

c. no long-range production investment strategy as part of the overall acquisition strategy.

d. unstable requirements and no reasonable match between requirements and existing process capabilities.

e. lack of programmatic focus on the need for balanced simultaneous product and process development.

4.2.3.2 Lack of attention to process capability. Risk factors during project development are due to:

a. insufficient or untimely consideration of producibility analyses.

b. product design instability resulting from an emphasis on meeting performance requirements without consideration of producibility.

c. insufficient identification of key product characteristics and key manufacturing processes.

d. late initiation of production planning and risk mitigation efforts.

e. lack of exit criteria for key processes and a lack of process related milestones.

4.2.3.3 Lack of consideration of process control. Risk factors that occur during production are due to:

a. lack of process control requirements for key characteristics and critical manufacturing processes.

b. deficiency in process improvement efforts.

c. lack of hard cost control requirements or incentives to control / reduce life cycle cost.

4.3 Success criteria. To achieve the MIL-HDBK-896A purpose, the following success criteria and supporting practices should be applied.

4.3.1 Balance product and process. Achieve balance in the consideration of product and process capability at the start of every phase of the acquisition process by:

a. balancing investments in both product and process during the preproduction program phases.

b. considering process capability in the technology development and technology insertion efforts.

c. incorporating evaluation criteria for production process capability in source selection with firm requirements for such issues as process development, process validation, process control, and production cost estimation.

d. implementing a well-defined production investment strategy as part of the overall acquisition strategy.

4.3.2 Balance product and process development. Achieve balance in the development of product and process during each phase of acquisition by:

a. identifying exit criteria for all key events and milestones appropriate to developing, establishing, and validating required process capabilities.

b. stabilizing the product design early in the development program through balanced trades between performance, cost, and schedule, with attention to producibility and supportability.

c. considering production-related issues such as Special Tooling, Special Test Equipment, and Support Equipment (ST/STE/SE) design and fabrication; and use of actual production processes to fabricate, assemble, and test prototype equipment to prove the manufacturing process.

d. using modeling and simulation of the design, production, and support environments.

4.3.3 Define the development and manufacturing environment. Establish a development and manufacturing environment that implements the practices of key characteristics, process controls, variability reduction, and defect prevention by:

a. requiring flow down practices which identify key product characteristics, key production processes, and key process parameters throughout the supply chain.

b. defining process control practices identified in the build-to data package.

c. implementing efficient variability reduction programs which improve dimensional control, yield higher product/process quality and reliability, and create an environment of preventive rather than corrective action.

4.4 Benefits. MIL-HDBK-896A practices represent a significant change in the way the defense industry operates. Achieving the full range of benefits available from the practices will require basic cultural changes on the part of all parties involved, from users

through low-tier suppliers. Some of the practices will require an up-front investment of material and/or labor during early development, with returns not realized until later in development and production. The commitment to make these up-front investments and continue the MIL-HDBK-896A practice activities throughout the life of the program is essential. The benefits resulting from implementation of MIL-HDBK-896A practices include:

a. shorter development schedules and reduced cycle times.

b. better product quality and reliability.

c. better development of robust product designs.

d. easier transition of designs to production.

e. better supplier product integration.

f. better risk management.

4.5 Relationship to airworthiness certification. Airworthiness certification, as governed by MIL-HDBK-516, contains specific manufacturing and quality criteria that must be met to attain airworthiness certification. These criteria include identification of key characteristics and critical processes, establishment of capable processes, and implementation of an effective quality system and process controls to ensure design tolerances are met. The practices within SAE AS6500 and this handbook are intended to satisfy those criteria. When SAE AS6500 is on contract and implemented effectively, the manufacturing and quality airworthiness criteria should be achieved. However, it is the responsibility of the Chief Engineer to verify the criteria have been met.

4.6 Relationship of SAE AS6500 to Manufacturing Readiness Level (MRL) Criteria. Manufacturing Readiness Levels (MRLs) are used to assess manufacturing risk and readiness. They provide a common understanding of the relative maturity, identification, and mitigation of manufacturing risks. TABLE I shows how the requirements of SAE AS6500 relate to the MRL threads. If the requirements of SAE AS6500 are effectively implemented, there is a high probability that the associated MRL thread will be at the target level.

TABLE I. Cross reference of MRL threads to SAE AS6500 requirements.

MRL Thread	SAE AS6500 Requirement
Technology and Industrial Base	6.4.1 Supply Chain and Material Management
	6.4.2 Manufacturing Technology Development
Design	6.2.1 Producibility Analysis
	6.2.1c Design Trade Studies
	6.2.2 Key Characteristics
	6.2.3 Process FMEAs
Cost & Funding	6.4.3 Cost
Materials	6.4.1 Supply Chain and Material Management
	6.5.8 Supplier Management
Process Capability & control	6.4.4 Manufacturing Modeling & Simulation
	6.5.3 Continuous Improvement
	6.5.4 Process Control Plans
	6.5.5 Process Capabilities
Quality Management	6.3 Manufacturing Risk Identification
	6.5.2 Manufacturing Surveillance
	6.5.3 Continuous Improvement
	6.5.7 FAIs/FATs
	6.5.8 Supplier Management
	6.5.9 Supplier Quality
Manufacturing Workforce	6.4.6 Manufacturing Workforce
Facilities	6.4.7 Tooling/Test Equipment/Facilities
Manufacturing Management	6.4 Manufacturing Planning
	6.4.5 Manufacturing System Verification
	6.5.1 Production Scheduling and Control
	6.5.2 Manufacturing Surveillance

4.7 Relationship of Manufacturing Management to Systems Engineering

Manufacturing management is closely linked to the systems engineering process in several ways. First, the manufacturing organization should provide representation to the design function and ensure producibility and inspectability are addressed as design considerations. Manufacturing engineers should provide process capability data to the designers and compare proposed tolerances, materials, and assemblies to current capabilities. Typically, a representative from the manufacturing function must coordinate on designs, indicating the design properly takes these considerations into account.

4.7.1 Address manufacturing during Design Reviews. Manufacturing is also a key topic to be addressed during the Systems Engineering Technical Reviews. Specifically, manufacturing readiness should be assessed and reported during Preliminary and Critical Design Reviews, with a focus on producibility and manufacturing risks. Of course, manufacturing readiness is the primary focus of Production Readiness Reviews. Further guidance on each of these reviews is included in IEEE 15288.2.

4.7.2 Include manufacturing management in the planning process. Manufacturing management should participate in the systems engineering planning process and contribute to systems engineering planning documents. The Systems Engineering Plan should include a discussion of manufacturing risks, staffing, metrics, and tools. It should also include an explanation of how manufacturing will be considered during the design and in technical reviews and audits. The Integrated Master Plan should include significant manufacturing events and reviews.

4.7.3 Track and manage manufacturing risks. Finally, the program's risk management process should include manufacturing risks, such as those identified through MRL assessments. Manufacturing risks should be tracked and managed using the same process as all other program risks.

5. ACQUISITION STRATEGY

5.1 Financial considerations. Two financial issues are associated with implementation of the approaches recommended in this guide. The first is a change in development of funding profiles to support doing the right task at the right time. This funding profile should include additional contractor costs and additional in-house government costs for increased government oversight and subject matter expertise. The second is recognizing the favorable impact that well-timed applications of these techniques will have on reducing the costs of design iterations in the later stages of development and ultimately reducing unit production cost. These considerations are reflected in different ways in each phase of a program, as described below.

5.1.1 Funding requirements for development and production. One of the most important business issues related to the implementation of SAE AS6500 and the guidance of this handbook is how to properly fund programs using these requirements. Implementing SAE AS6500 and MIL-HDBK-896A practices produces different funding profiles than those experienced on past programs, as illustrated on FIGURE 1.

5.1.2 Program funding comparison. In comparison to historic programs, programs that incorporate SAE AS6500 and the principles in this handbook require earlier funding, but the benefits of this earlier investment greatly reduce life cycle costs, including non-recurring production costs, through the substantial elimination of errors and change orders later in the program. SAE AS6500 requires manufacturing processes to be proven prior to the start of production and that there be early involvement of the manufacturing engineering discipline in the design process. As a result, inefficiencies in the manufacture of initial production units promise to be fewer and the producibility of the initial design will be improved over that of historical programs. These improvements more than offset early development costs.

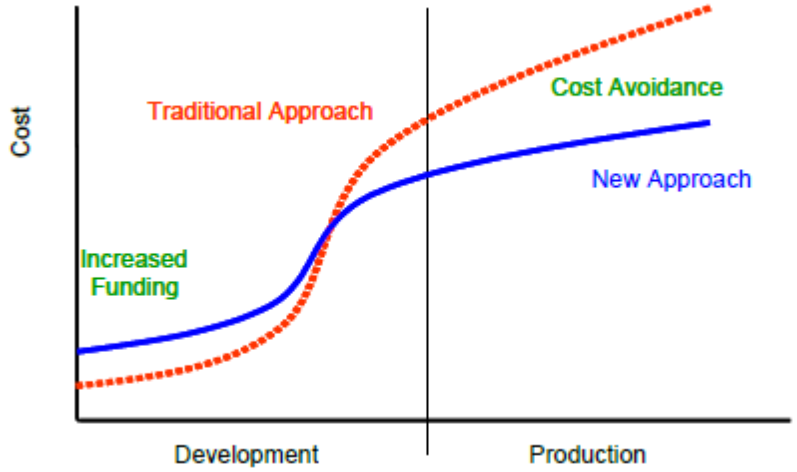

FIGURE 1. Comparison of MIL-HDBK-896A and traditional program funding profiles.

5.1.3 Cost estimating considerations.

5.1.3.1 Development phase. Cost estimating considerations for the development phase must now consider the effects of the additional SAE AS6500 and MIL-HDBK-896A activity. The standard and handbook promote several acquisition approaches that require greater effort up-front, such as producibility studies, assessments of manufacturing risks, earlier manufacturing process maturation, and modeling and simulation. Engineering and tooling hours shift to an earlier point in the program as design and manufacturing efforts are integrated sooner. The benefit, however, is that design changes can often be reduced by 50% or more. One program estimated MIL-HDBK-896A-related practices would have reduced tooling costs by 40%.

5.1.3.2 Production phase. Production phase costs and cost estimating will also be affected by SAE AS6500 and MIL-HDBK-896A initiatives. Early investments in manufacturing development will produce significant cost savings in production. Specific areas of increased production efficiency that can be expected from the use of SAE AS6500 and this handbook's practices include:

a. system redesigns significantly reduced. Traditionally, systems and processes have been designed in the development phase with changes made late in development through early production. This redesign and tooling rework effort should be significantly reduced.

b. design, quality, and manufacturing processes better integrated, resulting in a reduction of scrap, rework, and repair.

c. major subcontractors involved early in the design process, resulting in a more efficient integration of their components into the system and fewer supplier engineering change requests.

d. manufacturing labor costs start lower for first unit or T1 and proceed down a cost improvement curve that is below the historic non-MIL-HDBK-896A curve, as shown on FIGURE 2.

e. Better integration of the design, quality, and manufacturing processes result in lower first unit cost.

5.1.3.3 First unit costs run high. Traditionally, first unit costs run high due to the significant amount of manufacturing and re-manufacturing needed to incorporate design changes. The use of modelling and simulation tools, prior to the fabrication and assembly of hardware, enable the identification and resolution of problems prior to the actual start of manufacturing.

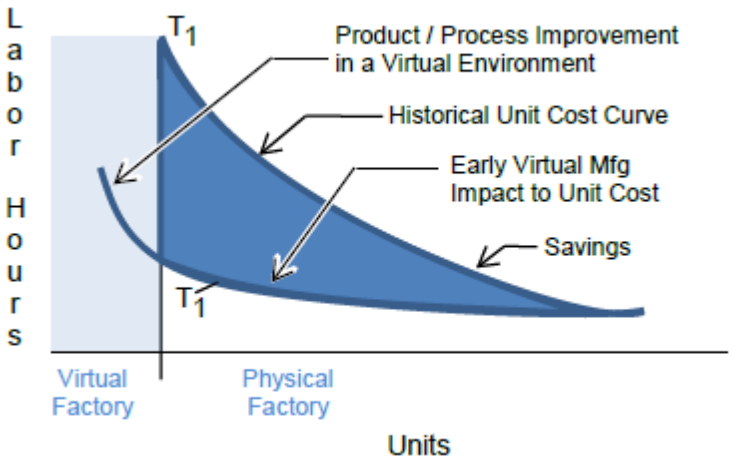

FIGURE 2. **Product/process improvement in a virtual/physical factory environment**.

5.2 Contracting considerations and request for proposal and Statement of Work (SOW) inputs. To ensure the implementation of SAE AS6500, the customer (such as a DoD program office or prime contractor) must cite it as a contractual requirement. Although some companies may implement it on their own, a recent Independent Review Team (IRT) discovered that contracts often lack contractual manufacturing management requirements, and, therefore, many best practices are not implemented.

SAE AS6500 was specifically written to be imposed contractually through an SOW requirement. This handbook serves only as a guide and should not be included in SOW requirements except to provide additional, non-binding guidance. A suggested SOW input is:

Example: "The contractor's Manufacturing Management Program shall meet the requirements of SAE AS6500."

5.2.1 Competitive purchases: The program office may determine that an offeror's manufacturing management system may be a discriminating factor in the award of the contract. In that case, Section L of the RFP may include the following to instruct the offerors to describe their manufacturing management system:

Example: "The offeror shall describe how their manufacturing management system meets the requirements of SAE AS6500."

5.2.2 Onsite survey inclusion. Since an onsite survey is a proven best practice during source selection, some programs may elect to add the following to Section L of the RFP:

Example: "The Government reserves the right to conduct an onsite survey to assess the offeror's manufacturing management system."

5.2.3 Proposal evaluation disclosure: Section M of the RFP should include the following statement to explain how the offerors' proposals will be evaluated:

Example: "This subfactor is met when the offeror's proposal describes how their manufacturing management system meets the requirements of SAE AS6500."

5.3 Tailoring guidance for contractual application. SAE AS6500 requirements can be applied as either full conformance or tailored conformance. Full conformance means that all of the requirements of the standard have been, or are being satisfied. Tailored compliance means that some of the requirements have been modified using a process agreed to by both the customer and the supplier. The contractor should be able to readily demonstrate compliance to either full or tailored requirements. Compliance can be demonstrated in two ways**:**

1. SAE AS6500 requires the manufacturing management system to be documented and the documentation describes processes for each of the requirements of the standard. Organizations that provide oversight can review the documented policies and procedures to ensure each requirement is adequately addressed.

2. The contractor should be able to provide examples of the analyses, work instructions, process control plans, and metrics that are required by the standard. The oversight organization can examine these products to determine if the processes and procedures are actually being implemented in accordance with the standard.

5.3.1 General tailoring guidance. Consider the following items when applying SAE AS6500 contractually.

a. The program's Acquisition Strategy Plan: Determine how SAE AS6500 relates to the overall program strategy and requirements.

b. The expected scale of program: Make sure SAE AS6500 requirements are appropriate to the size and scope of the program.

c. Documents referenced in SAE AS6500: If the program requires contractor compliance with any of the documents referenced in SAE AS6500, those documents must be called out separately in the contract.

d. The degree of Commercial Off-The-Shelf (COTS): Determine the extent to which COTS products will be used and how it impacts manufacturing requirements and planning.

e. Software: For programs that are primarily software in nature, SAE AS6500 may not be applicable.

f. TABLE II provides guidance for tailoring requirements of the standard. Each program leader determines specific requirements that apply to their specific situation. Examples of typical situations include:

1. Material Solution Analysis (MSA) phase
2. Technology Maturation and Risk Reduction (TMRR) phase
3. Engineering and Manufacturing Development (EMD) phase
4. production phase
5. sustainment phase (including supply support, spares, and repairs)
6. commercial derivative development (a commercially produced item modified for military use)
7. build-to-print production

TABLE II. Suggested application of requirements for typical situations.

Requirement	MSA	TMRR	EMD	Production	Sustainment	Commercial Derivative	Built to Print
6.2 Design Analysis for Manufacturing	Y	Y	Y	Y	As needed	Y	Y
6.2.1 Producibility Analysis	Y	Y	Y	Y	As needed	Y	N
6.2.2 Key Characteristics	N	Y	Y	Y	As needed	Y	As needed
6.2.3 Process FMEA	N	N	Y	As needed, to evaluate major design and process changes	As needed	Y	Y
6.3 Manufacturing Risk Identification	Y	Y	Y	Y	Y	Y	Y
6.3.1 Feasibility Assessments	Y	Y	N	N	As needed	As needed	N

TABLE II. Suggested application of requirements for typical situations - Continued.

Requirement	MSA	TMRR	EMD	Production	Sustainment	Commercial Derivative	Built to Print
6.3.2 MRL Assessments	Y	Y	Y	Y	Y	Y	Y
6.3.3 PRRs	N	N	Y	Y	N	As needed	As needed
6.4 Manufacturing Planning	N	N	Y	Y	Y	Y	Y
6.4.1 Supply Chain and Material Management	Y	Y	Y	Y	As needed	Y	As needed
6.4.2 Mfg Technology Development	Y	Y	As needed	As needed	As needed	As needed	N
6.4.3 Cost	Y	Y	Y	As needed	As needed	Y	As needed
6.4.4 Manufacturing Modeling & Simulation	Y	Y	Y	As needed, to evaluate major design and process changes	N	Y	N
6.4.5 Manufacturing System Verification	N	N	Y	As needed, to evaluate major design and process changes	Y	N	Y
6.4.6 Manufacturing Workforce	N	N	Y	Y	Y	Y	Y
6.4.7 Tooling/Test Equipment/Facilities	Y	Y	Y	Y	Y	Y	Y
6.5.1 Production Scheduling and Control	Y	Y	Y	Y	Y	Y	Y
6.5.2 Manufacturing Surveillance	Y	Y	Y	Y	Y	Y	Y
6.5.3 Continuous Improvement	N	N	Y	Y	Y	Y	Y
6.5.4 Process Control Plans	N	N	Y	Y	Y	Y	Y
6.5.5 Process Capabilities	N	N	Y	Y	Y	Y	Y
6.5.6 Production Process Verification	N	N	Y	Y	As needed	As needed	As needed
6.5.7 First Article Inspections	N	N	Y	Y	As needed	As needed	As needed
6.5.8 Supplier Management	Y	Y	Y	Y	Y	Y	Y
6.5.9 Supplier Quality	N	N	Y	Y	Y	Y	Y

5.3.2 Adapting SAE AS6500 to Maintenance, Repair, Overhaul (MRO) and Depot Activities. MRO operations are, essentially, manufacturing processes and share many of the same attributes as an OEM production line. MRO and depot functions include the induction of the unit to be repaired or overhauled, an evaluation of the unit to determine if there are problems that need to be addressed other than the planned work, some amount of disassembly, some re-manufacturing or refurbishment, re-assembly, test, and acceptance.

5.3.2.1 MRO lines benefit from SAE AS6500 planning tasks. Because of these similarities, MRO lines could benefit from many of the SAE AS6500 planning tasks, such as modeling and simulation, manufacturing system verification, and planning for tooling and test equipment. MRO operations, much like original production lines, require the application of SAE AS6500 manufacturing operations management activities, such as production scheduling and control, surveillance, continuous improvement, process controls and process verifications.

NOTE: Some differences between depots and OEM production are driven by the lack of new design activity during the Sustainment phase. As a result, the requirements within SAE AS6500 related to design analysis for manufacturing may not be applicable.

5.3.2.2 Supplier management at MRO and depot facility complications. Supplier management at MRO and depot facilities may be more complicated than what is typically experienced under an original production contract with a prime contractor responsible for both supplier management and final assembly. Depots may rely on supplier parts from a combination of prime contractors, lower tier suppliers, direct contracts with vendors, and parts purchased from separate supply chain management organizations. Application of SAE AS6500 supplier management requirements to each of these may be difficult and will depend on the contractual relationship with each of the organizations responsible for purchasing parts.

5.3.2.3 Addressing supplier management complications. If the MRO or depot function is being performed by a contractor, then SAE AS6500 can be placed on contract with the prime. It should be tailored appropriately, most likely by eliminating the Design Analysis requirements. For organic depots that are not governed by a contract or SOW, it is up to the program office or operational customer to require SAE AS6500 practices through whatever vehicle is used to task the organic depot. It is also up to depot organizations to take it upon themselves to become compliant with applicable SAE AS6500 requirements. Much like the initiatives to comply with ISO9001 or SAE AS9100, depot leadership should recognize the inherent benefits of applying best commercial standards and practices to their organizations to improve performance and remain competitive.

5.3.3 Adapting SAE AS6500 to limited production quantity programs. Limited production quantity programs can include space programs (launch vehicles, satellites, etc.) large ships and boats (aircraft carriers, submarines, etc.), and specialized aircraft (such as Air Force One). The small production numbers raise the frequently asked question of how manufacturing management can or should be applied in these situations.

5.3.3.1 Do limited production operations really have to be planned to the same level of detail as with a typical production program? Just as with the MRO operations discussed above, limited production programs can benefit from both the planning and operations management requirements of SAE AS6500. In addition, the design activities for these programs should consider manufacturing issues as described in SAE AS6500. The application of sound supplier management practices is especially important, given the critical application environments of the parts and the need to ensure quality in products that may not be accessible for repair (such as satellites). SAE AS6500 requirements cannot be dismissed outright and need to be analyzed, in detail, by subject matter experts to determine their proper application to low quantity programs.

5.3.3.2 Tailoring SAE AS6500 for limited quantity programs. SAE AS6500 should be tailored to meet the unique circumstances of limited quantity programs. In some cases, certain requirements may not be applicable. In other cases, the requirements may be applicable, but may need to be applied differently. Examples include:

a. Producibility analysis may still be applicable, but it should focus more on quality and manufacturability and less on the manufacturing cost effectiveness of the proposed design.

b. Modeling and Simulation typically focuses on factory processes, throughput, and capacity analysis and may not be required.

c. Process controls and variability reduction may still be applicable but process engineers may need to be more creative in their application. Even though only one end-item is produced, some processes can be repeated hundreds or thousands of times (such as with hole drilling or welding) and continue to lend themselves to statistical process controls.

5.4 Award fee inputs. The government program office may include an award fee as an incentive for the effective implementation of SAE AS6500. The following suggestions should be considered as starting points in developing award fee criteria. Once these plans have developed and are satisfactory, the Award Fee criteria should evolve to include evaluation of manufacturing, quality, and supplier management metrics. Examples include schedule performance, out-of-station work, scrap/rework/repair, Cost of Quality, process capabilities, and supplier delivery performance. Each program should tailor the criteria to fit their particular circumstances, priorities, and risks.

a. a manufacturing plan is available and it includes an approach for identifying key characteristics and critical manufacturing processes, and performing variability reduction activities and manufacturing capability assessments. The plan describes an active, aggressive producibility program.

b. a quality plan is available and it describes sound plans for implementing an effective Quality Management System that focuses on defect prevention.

c. a subcontract plan is available and it clearly describes implementation of a world-class supplier management organization that ensures exceptional supplier performance.

d. metrics have been established at the prime and with suppliers to accurately measure cost, schedule, and quality performance during development and to quickly provide supplier performance insight to the government using predictive indicators or other similar tools/techniques.

6. REQUIREMENTS

This section provides additional background, guidance, and lessons learned on the concepts contained in SAE AS6500. The topics are organized to parallel the SAE AS6500 structure.

6.1 Manufacturing management system. SAE AS6500 requirements stipulate contractors should have an overall manufacturing management system that documents organizational responsibilities for each requirement in the standard. Refer to Section 6.4, Manufacturing planning for additional information on documented manufacturing plans.

6.2 Design analysis for manufacturing.

6.2.1 Producibility analysis. Producibility should be considered as a part of design trade studies. The role of design trade studies in the manufacturing development process is to achieve a product design that effectively balances the system design with cost, schedule and performance elements to minimize total program risk. Institutionalizing producibility as part of the design trade study process is essential to an overall goal of affordable weapon system acquisition. Another excellent source for information on producibility programs is the Navy's NAVSO P-3687, "Producibility System Guidelines." This guide recommends a 5-step process:

1. establish a producibility infrastructure,
2. determine process capabilities,
3. address producibility during conceptual design,
4. address producibility during detailed design, and
5. measure producibility.

6.2.1.1 Identify production processes and economic impacts. The design trade study process should identify alternative production processes and consider the economic impacts of each alternative. Tools such as Taguchi Loss Function, Design of Experiments (DOE) or Quality Function Deployment (QFD) methods are valuable in evaluating the viability of design alternatives. The design trades should strive for robust product designs tolerant to variation in the intended manufacturing, assembly, test, and usage environments. They should be capable of identifying the design that represents minimum life cycle cost within program constraints. When key suppliers act as full members of the design team, the functional allocation and integration of all system components is enhanced.

6.2.1.2 Use trade studies to assess producibility. Trade studies should be conducted to assess the producibility of as many design concepts as time and cost allows, with level of detail and accuracy dependent on the relative contribution of each concept to achieving the production cost target or requirement. The introduction of new technology

can also introduce new design challenges. Utilizing concepts unproven in a production environment may result in severe cost and schedule problems. Environmental limitations must be addressed when analyzing alternatives. The benefits of utilizing commercial parts and processes and the affordability penalties resulting from the use of non-standard parts and processes should also be evaluated and documented in design trade-off decisions.

6.2.1.3 The cost of ignoring producibility issues. Programs that have not addressed producibility issues early in the product design and development cycle have experienced significant life-cycle cost increases due to lack of performance, excessive rework and repair, as well as costly redesign actions. The likelihood of a smooth transition from development to production is significantly enhanced by thorough monitoring and continuous application of the producibility initiatives.

6.2.1.4 Process capabilities. The manufacturing organization should communicate process capabilities to the design engineers so that tolerances can be determined based on the ability of the manufacturing processes to meet them. The manufacturing capabilities should be fed back into the design to result in a more producible product, consistent with the inherent capabilities of the existing processes.

6.2.1.5 Determinant Assembly is a producibility approach used to significantly reduce tooling and assembly costs. It relies on self-locating parts that have locating features directly on each mating part, as opposed to relying on expensive tools and fixtures for part placement. By applying this technique to position longerons to skins and bulkheads, a recent Air Force program was able to reduce aircraft assembly time by 1,200 hours per shipset in just one area.

6.2.1.6 Determine producibility effort targets. To determine where to target producibility efforts, assemblies can be evaluated using some or all of the following characteristics:

a. assemblies with high Realization Factor (RF)

b. assemblies which are time-consuming or difficult to assemble

c. assemblies consisting of many parts

d. assemblies consisting of expensive or difficult to manufacture parts

e. assemblies or parts which have experienced excessive failures in the field which could possibly be improved by a more robust design

f. areas having a high cost of quality

g. assemblies with a large number of shims

NOTE: Parts designed for use with Determinant Assemblies and monolithic parts that incorporate previous multiple individual parts can be a tremendous benefit to the assembly process. However, those unique parts may be difficult to support later in the life of the system. Designers must try to attain the optimum balance between standard and unique parts.

6.2.1.7 Successes. Successful implementation of producibility initiatives for the cargo floor of a recent aircraft program replaced 22 extrusions with 8 machined parts, resulting in installation of 4,000 fewer fasteners and a net program savings of $8.7 million in material, detail parts, and assembly cost over the life of the program.

6.2.1.8 Lessons Learned. The use of producibility and affordability engineering practices are most effective when they flow down to major/critical suppliers. Under performance-based specifications, the government relinquishes control of the detailed design to the prime contractor and suppliers, so those suppliers with design authority must also employ these tools and techniques.

6.2.1.9 Producibility Improvement Programs (PIP). PIPs should be formally documented and the documentation must include the baseline (before implementation) costs and post implementation costs, as well as the non-recurring costs to implement the initiative. It is often difficult to distinguish initiatives that are “over and above” the historical learning curves that were already used to estimate the program costs. Historical learning curves usually include some amount of cost reduction initiatives, so the challenge in documenting and estimating the impacts of new projects is to determine if they are truly over and above what has been done in the past. Generally, initiatives that reduce the scope of work can be considered over and above, but the ones that improve the efficiency of the work must be more carefully evaluated.

6.2.1.10 Cost plus fixed fee on producibility efforts. One major DoD program found that producibility efforts should not be placed on a contract using a Firm Fixed Price option. Although an acceptable level of effort for producibility activities was negotiated, once on contract, higher priority work at the prime contractor prevented the agreed-to level of effort from being accomplished. Since no specific results or products were required in the contract, there were no penalties for not putting forth the effort. As a result, the contractor achieved a high profit rate and the affordability and producibility of the product was not improved significantly. Instead of a Firm Fixed Price contract, a Cost Plus Fixed Fee contract is recommended.

6.2.1.11 Remain open to additional cost saving ideas. A program found return multiples (also known as Return on Investment) may approach 15 or 20 to 1, for initiatives implemented early in a program. As the program progresses through production, the return multiple is typically expected to decrease, primarily due to the reduced number of units that experience the benefits. However, a program found the benefits do not decrease because the easy, “low hanging fruit” is exhausted early (as many would expect). Rather they continued to find ideas that resulted in large payoffs. Therefore, the program should continue to search for new projects even after the initial round of projects has been identified and implemented.

6.2.1.12 Consider producibility early in the design process. Historically, efforts have relied on serial development between product and process. Almost all development emphasis was placed on system performance during pre-production. When the required performance was functionally demonstrated, attempts were made to transition the design to production. The manufacturing function tried to adapt existing processes to

manufacture the qualified design. Considering producibility earlier in the design process promises a smoother transition to production.

6.2.2 Key Characteristics (KCs) and processes. FIGURE 3 provides the definition of a KC. The identification of key product characteristics and key production process capabilities is a basic engineering task essential to successful manufacturing development. The objectives of this practice are:

a. identify product characteristics of the design which most influence fit, performance or reliability;

b. support the mapping of product characteristics to production processes;

c. enable the balancing of product design requirements with manufacturing process capabilities; and

d. enable the development of the required process controls for production.

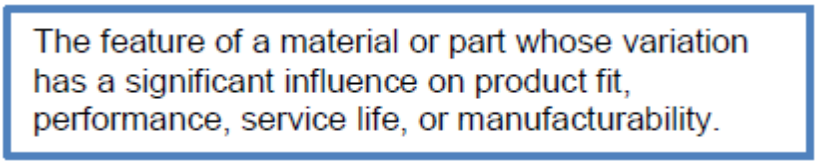

FIGURE 3. Key Characteristic (KC) definition.

6.2.2.1 Key Characteristics Function. The concept of identifying key characteristics is linked to the Pareto principle, which asserts that a relatively small number of features will have the most significant impact on performance. This principle enables the program to focus scarce resources on the most critical features and processes. Identification of KCs should ideally begin in the earliest phases of development, with the list of KCs continuing to be refined. Early in development, a list of preliminary KCs should be identified. As the development phase progresses, the list should mature to a final list of KCs. As the KCs are finalized, the corresponding list of critical processes should also be completed. Later in development the list of KCs should be reduced as the product design is refined to make key characteristics less sensitive to variation. The practice of identifying KCs serves many purposes. Among them:

a. Facilitating communication among design and manufacturing engineers by linking the competing objectives of performance and producibility together in a common point of reference on the part or system. Many KCs are interface characteristics, so their identification requires enhanced communication between engineering and manufacturing as well as among prime contractors and suppliers.

b. Identifying characteristics to be redesigned or eliminated in order to achieve a more robust product design.

c. Identifying characteristics for which manufacturing process capabilities must be assessed.

d. Identifying candidate key characteristics for future variability reduction activities.

e. Identifying product characteristics that are most important and may require extra attention in the manufacturing process, such as the use of statistical process control techniques.

f. Assist in selection of suppliers that already have process control in place for the processes that are high contributors to product variation.

6.2.2.2 Identification of KCs: Contractors have used a wide variety of approaches for identifying KCs. Subjective approaches, such as general discussions and consensus among design and manufacturing experts may be used. More objective and rigorous tools are recommended, including Quality Function Deployment, detailed risk identification methods, or statistical analysis of yield and reliability data from similar products.

NOTE: Key Characteristics should be used to control the quality of parts designated as Critical Safety Items (CSIs) or Critical Application Items (CAIs).

6.2.2.3 KCs and critical characteristics comparison. It is important to distinguish between Key Characteristics and Critical Characteristics. As defined in DOD-STD-2101 (Classification of Characteristics), a Critical Characteristic is one that "analysis indicates is likely, if defective, to create or increase a hazard to human safety, or to result in failure of a weapon system or major system to perform a required mission." A Critical Safety Item is a part that contains a characteristic for which any failure or malfunction could cause a catastrophic or critical failure resulting in the loss or serious damage to the aircraft or weapons system, an unacceptable risk of personal injury or loss of life. Per the Aviation Critical Safety Item Management Handbook, Critical Characteristics identified on CSIs must undergo 100% inspection, unless the government has approved a sampling or Statistical Process Control approach. In addition to aviation CSIs, NAVSEA Instruction 9078.1 defines CSIs for naval ships as any ship part, assembly, or support equipment containing a critical characteristic whose failure, malfunction, or absence may cause a catastrophic or critical failure resulting in loss or serious damage to the ship, or unacceptable risk of personal injury or loss of life. The NAVSEA instruction also requires stringent quality controls on CSIs.

6.2.2.4 Critical Characteristics (designated as Key Characteristics). This may be done to trigger the quality system to develop a process control plan and to institute variability reduction efforts. In some companies, the KC management process may be better defined and more visible than the process to manage Critical Characteristics. Identifying Critical Characteristics as KCs may also facilitate and improve communication with suppliers. Since the flow down of KCs may be a well-understood process, it could be an ideal method to ensure a supplier understands the criticality of characteristics flowed down to them for fabrication or assembly.

6.2.2.5 Lifespan of a KC. By definition, there should be relatively few KCs. Although there is no magic number that is universally applicable, each major part may have 1-3 KCs, and most simple parts (such as clips and brackets) should have none (although even simple parts may have KCs). Once identified, KC status is not permanent.

KCs are changeable over time and may be deleted as the design is changed. New KCs may also be added as the design is refined.

6.2.2.6 KC assessment. If KCs are identified for assembly characteristics (such as fit, gaps, etc.), then the design for the parts composing the assembly must be assessed to determine if KCs exist for each of those parts. Through this approach, higher level KCs may be flowed down to the lowest possible level to ensure controls in fabrication. A common question that arises is, “Should KCs be deleted when the manufacturing process is highly capable?” By definition, the stability, capability, or maturity of a process is not a factor in the designation of a feature as a KC. KCs can serve as an important communication tool to other producers of key features. For instance, a part may be re-competed and made by a new supplier or turned over to a depot for sustainment support. In these examples, the continued designation as a KC communicates the criticality of the feature to the new supplier. If current processes are highly capable, the process control plan should be adjusted to reduce inspections. In addition, use of highly capable processes may reduce the amount of attention and documentation required. Another frequently asked question is whether KCs need to be identified on programs with very low production quantities. KCs should be identified regardless of the anticipated quantities. The definition of KC is independent of quantity. If a characteristic is important, that criteria needs to be communicated to the manufacturing and quality organizations so they are aware and treat the characteristic with due care. Process control plans must still be developed to ensure the quality of the KCs. Those process control plans may rely less on statistical process control methods, given the low numbers, but added attention needs to be given to characteristics that are key to the proper function of the system. Even if the overall production quantities are low, some critical processes related to KCs may be repeated hundreds or thousands of times (such as hole drilling).

6.2.2.7 KC identification. KCs should be identified on drawings or in specifications. One method is to use a flag, as shown on FIGURE 4 which shows KCs relating to low observability properties. A unique identifying number or label should be assigned to each KC so that related data can be tracked and mapped to the production processes that create the KCs.

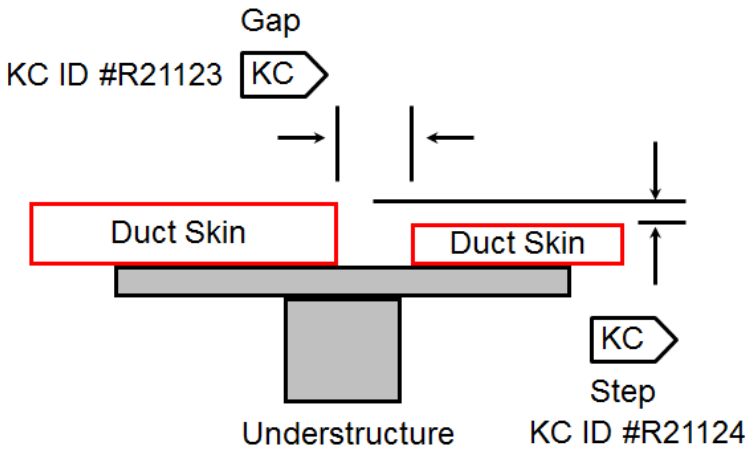

FIGURE 4. KC Flags on drawing.

6.2.2.8 Mapping critical processes to KCs: Once identified, the team must determine which manufacturing processes create or significantly contribute to each KC. These processes are then termed critical processes. The contractor should maintain documentation depicting this relationship between each KC and their associated critical processes. For each critical manufacturing process, a Process Failure Modes and Effects Analysis (FMEA) should be performed and process control plans should be developed and implemented.

6.2.2.9 Identify key process characteristics. For each critical process, the key process parameters (also known as key process characteristics) must be identified. Key process parameters are process inputs (such as temperature, time, pressure, etc.) that have a significant impact on the product being produced in that process and must, therefore, be strictly controlled. In some cases, the prime contractor may flow down specific key characteristics to a supplier, especially if the supplier is producing to a design provided by the prime. Suppliers who have design authority, however, should have responsibility to identify their KCs and critical processes. In either case, the prime should have a plan for managing production of products with key characteristics at suppliers.

6.2.2.10 KCs on avionics. The question frequently arises as to whether or not Key Characteristics can be applied to avionics items. When it comes to KCs on avionics, there are two general approaches. The first is to identify KCs on mechanical aspects of the parts (solder characteristics, part dimensions, etc.) that would impact either the integrity of the part or its physical integration into the next higher assembly. The second approach is to identify electrical performance parameters as KCs. These may include voltage ranges, activation times, frequency responses, etc. Both of these approaches are valid and have been used.

6.2.2.11 Additional guidance. Additional guidance on Key Characteristics can be found in SAE's aerospace standard SAE AS9103, "Variation Management of Key Characteristics." This handbook and SAE AS6500 are intended to be consistent with SAE AS9103. SAE AS9103 may be included in the SOW alongside SAE AS6500 to provide additional requirements for KCs and Variation Management.

6.2.2.12 Lessons learned. The benefits gained from improved communication and coordination between various organizations, as a result of identifying KCs, cannot be overstated. Including cross-functional (and often cross-company) representatives at the same table to determine critical interfaces and features can result in huge dividends. In a major airframe program, this type of coordination resulted in major structural sections fitting "like a glove," despite being designed and built by different companies, which were geographically separated, and used different materials and processes. The identification of too many KCs can be a potential pitfall. Each KC costs the manufacturing organization money. They must develop control plans and collect, analyze, and act upon data. Too many KCs can be caused by:

a. misunderstanding of the definition of KCs,

b. overly-cautious product design engineers who see KCs as an opportunity to tighten the reins on manufacturing, and

c. the desire for manufacturing data.

6.2.2.13 KC considerations. In one large aircraft program, engineers chose weight as a KC, not because it met the definition of a KC, but because they wanted a great deal of weight-related manufacturing data. Training of all IPT members is the key for preventing too many KCs from being chosen. Metrics can be an area of conflict when it comes to measuring progress in selecting KCs. While tracking the total number of KCs identified to-date is informative, managers must use the data judicially, since there are generally no "good" or "bad" trends or criteria and numerical goals are meaningless. Typically, early in a program, the number of KCs should be expected to rise as new KCs are identified; later in development they should be slightly reduced as some are designed away. However, those who compile data for the metric can be inundated with requests to needlessly explain every change from reporting period to reporting period. The ultimate goal is that each KC should have proven acceptable capability. A recent IRT discovered that design documentation does not consistently identify safety-critical features. As a result, no special emphasis is communicated to manufacturing, quality, or purchasing organizations, or through the supply chain. To help correct this situation, key characteristics should be identified on items that are critical to safety. KCs can serve as an excellent communication tool among organizations and suppliers to indicate the criticality of those items. They will also help control the quality of safety-critical items by ensuring they meet design requirements.

6.2.3 Process Failure Modes and Effects Analysis (PFMEA). Process Failure Modes and Effects Analyses (PFMEA) provide a structured risk based methodology for analyzing and preventing failures in manufacturing and assembly processes. The PFMEA is a process design risk analysis tool, and it should be performed continuously from conceptual design through development. The objectives of PFMEAs are:

a. identify the potential failure modes of a process and the effects of those failures;

b. rank risk probability and consequence associated with failure modes; and

c. develop actions that will mitigate or eliminate the probability and/or consequence of the potential failures.

6.2.3.1 Early recognition. Timeliness of the analysis is important because it can be used to identify and eliminate failure modes before they are incorporated into a new production process. Alterations to the manufacturing process or improvements to the product design based on PFMEA in the development phase are more easily implemented at a lower cost. Whenever a design or process change is implemented, the analysis should be renewed and the worksheets that document the analysis should be updated.

6.2.3.2 PFMEA benefits. Conducting a PFMEA during process development permits early problem identification and resolution. This technique focuses on the prevention of non-conformance rather than detection. A thorough application of the PFMEA can identify foreseeable modes of failure within a process design, especially catastrophic or safety related failures. The shortcomings of the manufacturing process can

then be resolved during manufacturing process design. Failure modes that cannot be entirely resolved can be recognized and mitigated. In many cases, recognition of the risk of failure during manufacturing can also be fed back into product design, and a more robust product design that is less sensitive to certain manufacturing processes can mitigate risk. By reducing failure points and thereby increasing process quality, we should be able to reduce production, operational and maintenance costs. PFMEAs are especially valuable to analyze critical manufacturing processes where the PFMEA prevents defects that are most relevant to safety and mission performance of the part or system. They can also be used to reduce cost on high dollar value parts and parts with manufacturing processes that have a high scrap and/or rework cost. DoD, prime contractors, and suppliers should realize the following benefits:

a. increased quality because of a more thoroughly engineered manufacturing process.

b. cost savings by reduction of rework

c. cost reduction by identification of potential errors earlier in the life of the system.

d. better understanding of the effects of potential failures on the customer

e. upgraded production performance from process improvement efforts based on a prioritized list of potential failure modes

f. improved Customer Satisfaction due to development of products with greater quality and reliability

6.2.3.3 Guidance. Initiate PFMEA analysis as soon as product design has progressed far enough to initiate manufacturing process development. PFMEAs should be repeated/updated whenever there is a new process, a modification to an existing process, or when an existing process will be used in a new environment, location or application. The level of effort, sophistication and scope of the PFMEA should be thoughtfully tailored to each application. An Ishikawa diagram (also called a fishbone diagram) may be useful for some steps in the PFMEA. Development and maintenance of PFMEA process worksheets is important to ensure continuity for follow-up analysis.

6.2.3.4 Design Failure Modes and Effects Analyses (DFMEA). DFMEA is a design analysis technique used to identify potential problems with the product design and to eliminate or mitigate those problems before the design is finalized. PFMEAs are not intended to take the place of DFMEAs, since they cannot improve the quality or reliability of an inherently poor design. Manufacturing and Quality Engineers should contribute to DFMEAs early in development. Outputs from the DFMEA should feed into the PFMEA to provide the most robust transition to production.

6.2.3.5 Failure Modes, Effects and Criticality Analysis (FMECA). Some literature on FMEAs includes a criticality analysis of each of the items and failure modes being analyzed to determine which are most important. If this analysis is conducted, the term becomes Failure Modes, Effects and Criticality Analysis (FMECA). However, when developing SAE AS6500, the SAE committee decided against the mandatory imposition of the criticality analyses due to added costs to perform the analyses. Therefore, SAE AS6500

uses the PFMEA terminology. A worksheet is useful for tracking the PFMEA process. Worksheets should document the ten steps described below:

1. **Process Function**. This is a concise statement of the function of the manufacturing process (examples include; polishing, deburring, drilling or assembling). Supporting information should be included to put the process function into context. Indicate the purpose of the process and include metrics for performance.

2. **Potential Failure Mode**. A potential failure mode is a way in which the process or part can fail to meet specifications, or otherwise dissatisfy the customer. Describe the potential failure as a physical nonconformance of the process output (examples include; bent, cracked, handling damage, hole off-location). All predictable failure modes for each component, sub-system and process characteristic should be identified and described.

3. **Failure Effects**. Failure effects are the consequences to the customers for each potential failure mode. The failure under consideration may affect multiple levels of the system. Because of this, local, next higher level, and end effects should be evaluated. For each level of the system, also consider each customer. The local effect is typically the failure mode itself, but may also be stated in terms of effects on the local process (cannot assemble, damages equipment, causes excessive tool wear, endangers operator). For downstream manufacturing operations, failure effects should be stated in terms of process performance. End effects are those seen by the user, and the effect a failure mode has on the operation, function or status of the global manufacturing process. These effects should be stated in terms of product or system performance (examples include; noise, intermittent operation, rework/repairs, poor appearance).

4. **Severity**. Severity is a subjective numerical rank given to each failure effect. It considers the worst potential consequence of a failure, determined by degree of injury, interruption to the process, or damage to the system. The PFMEA team should agree on ranking criteria appropriate to the analysis. The ranking criteria should create categories of failure effects (examples include; minor, marginal, critical and catastrophic). The categories are then numbered and a numerical rank assigned to each failure effect.

5. **Causes**. This is a description of the potential causes of a failure mode, written in terms of something that can be controlled or prevented (examples include; Inaccurate gauging, worn locator, improper heat treating, inadequate lubrication). Avoid ambiguous naming of causes (examples include; operator error, machine malfunction). Causes will often be interrelated and a design of experiments or similar method may be necessary to discover major causes that can be controlled.

6. **Occurrence**. Occurrence is the probability that a specific failure mode will happen. Occurrence is numerically ranked in the same manner as severity. Historical failure rate data should be used if it is available. Statistical data from similar processes can be used as a basis for determining occurrence. Otherwise, the team may perform a subjective assessment.

7. **Current Process Controls**. This is a description of the existing controls that either prevent or detect potential failure modes. Prevention controls are preferred and may

include methods such as statistical process control (SPC) or error proofing. Detection controls may include gauging, manual inspection or inability to pass a bad part.

8. **Detection**. Detection is the probability that a failure will not be detected. Detection is numerically ranked in the same manner as severity and occurrence. The probability of non-detection is established in the same manner as occurrence.

9. **Risk Priority Number**. Risk priority number (RPN) represents failure mode criticality. This is a simplified but effective version of criticality analysis. The RPN is the product of severity (S), occurrence (O), and detection (D):

$$RPN = S \times O \times D$$

NOTE: The potential failure modes with the highest RPNs are the most critical, and deserve the most attention. Items with very low RPNs may not warrant action.

10. **Recommended Actions**. Actions should be developed with the purpose of lowering the RPNs. Once the highest RPNs are addressed, the team can continue to address the next highest risk areas. The actions should endeavor to reduce rankings in the following preference order: severity, occurrence, and detection. Emphasis is placed on preventing failures rather than detecting them.

6.2.3.6 External guidance. Military standard methods for conducting a Failure Modes, Effects, and Criticality Analysis (FMECA) were detailed in MIL-STD-1629A. This MIL-STD was cancelled on August 4, 1998. The cancelled standard gave guidance to consult various national and international documents for information regarding failure mode, effects, and criticality analysis. The standard was written for product (design) FMECA, and no guidance was provided for applying the FMECA to manufacturing or assembly processes. An industry standard method for conducting a Potential Failure Modes and Effects Analysis in Manufacturing and Assembly Processes (PFMEA) can be found in the Society of Automotive Engineers (SAE) surface vehicles recommended practice document J1739 (SAE J1739). The PFMEA methodology in SAE J1739 uses a different type of criticality analysis than MIL-STD 1629A. The SAE PFMEA methodology is well suited to manufacturing processes and is recommended. Another source of information is the document “Potential Failure Mode and Effects Analysis” from the Automotive Industry Action Group.

6.2.3.7 Lessons learned. To be effective, the application of PFMEA must correspond with the nature of the process itself and ultimately each PFMEA is a uniquely performed analysis. Because it contains subjective measurements, it is not appropriate to compare the results of different PFMEAs, even those performed by the same individual or team. The analysis should be assigned to individuals familiar with the system or similar systems. If the PFMEA is treated as a box checking, CDRL-fulfilling exercise it will be of little use. Seven common sources of failure in contractor performed PFMEA are identified below. Teams assigned to do PFMEAs should take steps to avoid these potential pitfalls:

1. **Untimely undertaking**. The PFMEA must be scheduled and completed concurrently with the design of the manufacturing and assembly process so that the product designs will reflect its analysis, conclusions, and recommendations.

2. **Insufficient Recognition of Failures and Causes**. The discovery of failures and their causes is essential to the PFMEA task. Potential failure modes must be explained and not simply named. Make sure failure modes are not confused with effects or causes. An understanding of the process functional requirements is requisite to understanding potential failure modes, effects, and their causes.

3. **Failure to properly identify the customer**. The customer will typically be identified as the end user, but can include downstream manufacturing or assembly operations.

4. **Too narrow in scope of analysis**. The contractor should be sure to explore the effects of multiple failures, degraded conditions, and downstream effects. After establishing potential failure modes for a particular process, consider the effects in relation to the entire system and all customers.

5. **Weak recommendations**. A common pitfall is a failure to recommend actions that resolve the risk, or to develop actions that are neither actionable nor executable.

6. **Improper failure classification**. Potential failure modes must be accurately classified. Trivializing or hiding potential safety items or failure modes must be avoided. Similarly, occurrence and detection must not be treated with too much optimism.

7. **Ignoring existing system data**. Failure data and history of very similar systems should be considered.

PFMEAs can be used to identify opportunities to mistake-proof (Poka Yoke) manufacturing processes. Foreseeable modes of failure with high risk priority numbers should, as part of their recommended actions, include mistake-proofing devices or processes. Several IRTs found that mistake-proofing is an underused approach and even a moderate implementation of its concepts would have prevented several high-profile weapon system failures.

6.3 Manufacturing Risk Identification

6.3.1 Manufacturing Feasibility Assessments. Manufacturing Feasibility Assessments are typically performed early in the life cycle when competing design concepts are being considered. The assessments are conducted to identify potential manufacturing constraints and risks and the capability of the contractor to execute the manufacturing efforts. Assessments should be made for each competing design alternative under consideration and they should:

a. Identify required production processes and manufacturing techniques not currently available and the risks associated with development of manufacturing technologies, the probability of meeting the need dates and possible contingency actions.

b. Identify potential impact of critical and long lead time material and production equipment, the probability of meeting the need dates and possible contingency actions.

c. Provide production feasibility, design performance, cost, and schedule impact analyses to support trade-offs among alternatives.

d. Provide cost and production schedule estimates to support management reviews.

e. Determine an efficient rate of production and rate acceleration curve.

f. Make recommendations for anticipated production testing and demonstration efforts, including specific requirements for production run demonstrations using production tooling, test equipment, and manufacturing equipment.

g. Develop methods of conserving critical and strategic materials and of reducing reliance on foreign sources.

h. Identify potential production bottlenecks and limiting factors to rate production.

6.3.2 Manufacturing Readiness Level (MRL) Assessments. An excellent approach to identifying manufacturing risks is the Manufacturing Readiness Level Assessments. MRL Assessments were developed by OSD's Joint Defense Manufacturing Technology Panel, and evaluate production maturity using Manufacturing Readiness Levels ranging from one to ten. The intent was to create a measurement scale that would serve the same purpose for manufacturing readiness as Technology Readiness Levels serve for technology readiness – to provide a common metric and vocabulary for assessing and discussing manufacturing maturity, risk, and readiness. MRLs were designed with a numbering system to be roughly congruent with comparable levels of TRLs for synergy and ease of understanding and use.

6.3.2.1 Assessment of risk. Manufacturing readiness, like technology readiness, is critical to the successful introduction of new products and technologies. Manufacturing Readiness Levels (MRLs) represent a new and effective tool for the DoD S&T and acquisition communities to address that critical need. MRLs are designed to assess the maturity and risk of a given technology, weapon system or subsystem from a manufacturing perspective and guide risk mitigation efforts. MRLs are also intended to provide decision makers at all levels with a common understanding of the relative maturity and attendant risks associated with manufacturing technologies, products, and processes being considered to meet DoD requirements. They provide specific criteria to support decision-making based on knowledge of manufacturing status and risk.

6.3.2.2 MRL criteria. The criteria for Manufacturing Readiness Levels are organized into threads, such as Design, Materials, and Process Capability & Control. Many of the MRL criteria are closely tied to SAE AS6500. For example, MRL criteria address producibility studies, key characteristics, production cost models, and quality systems. Therefore, implementing the practices described in this handbook and SAE AS6500 will enable successful achievement of target MRLs. Objective criteria are provided for each level to reflect the growing expectation of maturity as the program progresses through its life cycle. During the early MRL phases, manufacturing feasibility is the only expectation. As a program progresses through development, the MRL criteria become more stringent and production representative manufacturing processes are anticipated. At the finish of the EMD phase, programs should make use of the same tooling, test equipment, workforce, work instructions, and methods that will be used during the Production phase.

NOTE: An MRL Assessment is a snapshot of manufacturing maturity at a moment in time. This practice may also be performed on an ongoing basis, as part

of the program's risk management process. It may also be implemented as a special, targeted review of manufacturing capability.

6.3.2.3 MRL Assessment benefits. In the defense acquisition environment, risk has often become an issue when the contractor/government acquisition team overestimates technology readiness, downplays potential transition to production problems, or fails to plan and perform effective risk management. The results frequently have included cost overruns, schedule delays, and technical compromises. MRL Assessments have been used successfully to identify and mitigate manufacturing risks. One specific success story includes an Air Force bomber modification program. The program office personnel, in conjunction with the prime contractor, assessed a dozen key suppliers and identified numerous risk areas that required risk mitigation plans. The identified risks ranged from product oriented actions (design changes and diminishing manufacturing source issues) to factory process improvements (quality and production control systems). The program office firmly believed that, had the MRL process not been in place, many of these risks would not have surfaced until the program started production, resulting in cost and schedule impacts. MRL Assessments can also provide benefits to the prime contractors and suppliers. In some instances, where there is limited government program office manning, the government engineers and program managers may not be aware of issues at lower tier suppliers. In the case of another Air Force bomber modification program, the MRL assessment revealed diminishing manufacturing source issues at suppliers for which the government had to take action to resolve. The contractors were pleased to be able to elevate the issue to the government customer. In another example, The MRL assessment for a piece of personal protection equipment identified the need for additional manufacturing technology development. This finding led the government to allocate additional funding for the contractor to improve manufacturing process yields, which improved schedule confidence and reduce cost. Go to www.dodmrl.com, for additional information on MRLs and MRL Assessments.

6.3.3 Production Readiness Reviews (PRRs). The program-level PRR is a Systems Engineering Technical Review at the end of EMD that determines if a program is ready for production. MRL 8 is the target for Low Rate Initial Production (LRIP) and MRL 9 is the target for Full Rate Production (FRP); these targets should be reflected in the acquisition program baseline. The PRR assesses whether the prime contractor and major subcontractors have completed adequate production planning and confirms that there are no unacceptable risks for schedule, performance, cost, or other established criteria. Generally, incremental PRRs (iPRRs) are conducted at the prime and major subcontractors in the year leading up to the milestone decision, and a formal Executive PRR is conducted at the conclusion of the iPRR process. The Executive PRR report includes a recommendation to the Milestone Decision Authority regarding the program's readiness for production. The PRR process is an on-site, structured examination of the program's readiness for production, and should include comprehensive evaluations in the following areas: Industrial Resources, Production Engineering & Planning, Quality Assurance, Material & Purchased Parts (Supply Chain Management), Engineering & Product Design, Software, Logistics, and Program Management. An assessment of manufacturing maturity and risk, conducted by manufacturing subject matter experts, should be a principal area of emphasis during the PRR. That portion of the PRR should review the readiness of the

manufacturing processes, the quality management system, and the production planning (including facilities, tooling and test equipment capacity, personnel development and certification, process documentation, inventory management, supplier management).

6.3.3.1 When to conduct PRRs. In the case of incremental acquisitions, PRRs should be conducted for each major increment. PRRs, or Production Assessment Reviews, should also be conducted whenever major changes to the production system warrant additional review, even if they occur after the full-rate milestone decision. Examples of changes that might trigger a follow-on review are movement of the production facility, large-scale tooling changes, major supplier changes, and the onset of significant production problems.

6.3.3.2 MRL Assessments with PRRs. The assessment of manufacturing readiness should highlight any areas where an element or a key program-level manufacturing preparation area falls short of MRL 8/9 requirements; discuss the risks that these shortfalls pose to the program and the status of efforts to mitigate these risks; and estimate the schedule or funding changes required to correct any significant shortfalls.

6.3.3.3 MRLs with PRRs. The MRL methodology may be used to assess the manufacturing, quality, and supplier management elements of a program. In addition, the scope of PRRs may include other functions, such as Test, Logistics, and Program Management.

6.4 Manufacturing planning SAE AS6500 requires a manufacturing plan and lists the topics that should be addressed in the plan. Overall, the plan should describe how their manufacturing management system meets the intent and requirements of the standard. The program office should require a deliverable manufacturing plan. In this way the government provides added attention and focus to manufacturing planning and has the opportunity to influence the manufacturing approach. The plan should be developed prior to Milestone B (if possible) or during EMD. The program office should require updates to the plan throughout the production phase. TABLE III lists the topics to be addressed in a manufacturing plan, per SAE AS6500, and some guidance on each topic. It also lists sections of this handbook that may provide additional insight or background on the topic.

TABLE III. Manufacturing plan guidance.

Topic	Handbook Reference	Notes
Manufacturing methods and processes	6.2.2, 6.3.2, 6.5.1	Discuss the planned manufacturing methods and processes to produce the product. Include a major assembly sequence chart which identifies the key / critical processes relating to fabrication, inspection, and test. Discuss the maturity of the processes and associated risks. Manufacturing process maturity can be evaluated by performing Manufacturing Readiness Level assessments (www.dodmrl.com).
Manufacturing technology investments	6.2.1, 6.4.3	If applicable, discuss anticipated investments in the development or use state of the practice manufacturing technologies. (For example, additive manufacturing, cold spray to improve product quality and production yields.)
Production control	6.5.1	Discuss the production control system, how it schedules work and resources, and how it ensures configuration control. Explain how planning will be verified prior to production.
Producibility	6.2.1	Discuss the producibility process and specific, anticipated producibility projects.
Material management	6.4.1.1, 6.4.1.2, 6.5.8.1	Discuss how make-or-buy decisions are made and how suppliers are chosen and managed. Discuss the process controls (critical parts list, obsolescence management, counterfeit parts and material prevention) that are in place or will be in place, to minimize product vulnerability due to the unavailability, or untimely delivery of materials supplies. Identify long lead items and associated schedules depicting procurement dates and need dates.

TABLE III. Manufacturing plan guidance - Continued.

Topic	Handbook Reference	Notes
Manufacturing system verification	6.4.5, 6.5.6	Discuss how the planned manufacturing processes including the requirements for materials, test equipment, tooling, equipment, personnel skills, facilities, and related software will be verified to ensure they can meet production rate requirements. A pilot manufacturing line could be established to verify and test manufacturing methods, processes and procedures.
Minimization of scrap, rework, and repair	6.2.3, 6.5.3,6.5.4, 6.5.5	Discuss the tools and defect detection and prevention techniques that will be employed to ensure the quality of the products. These detection and prevention techniques may include inspection, test, defect trend analysis, and Statistical Process Control.
Facilities	6.4.4, 6.4.7	Discuss the planned facilities and how they will meet the production needs. Ensure a facility review has been conducted that identifies the necessary facility requirements such as test equipment, training aids, building size, plant layout, and any other special considerations needed to support production rates.
Test equipment	6.4.7	Discuss the anticipated tooling and test equipment and the schedule for developing, procuring, and verifying it is ready prior to the need dates.
Capital commitments	6.4.3, 6.4.7	If applicable, discuss capital investments for production relevant resources (equipment, tooling, material) that is needed to meet production requirements.

TABLE III. Manufacturing plan guidance - Continued.

Topic	Handbook Reference	Notes
Personnel, skills, training	6.4.6	Discuss the planned approach to acquire and train the workforce, including any special skills or certifications required. Provide a forecast of required manpower loading, by skill, over time.
Customer furnished items	N/A	Discuss what customer furnished equipment or property is needed and the estimated quantity and need dates.
Customer inspections	6.5.8.2, 6.5.9	Discuss plans for acceptance testing and the role of the government in product acceptance.
Capacity analysis	6.4.4,6.4.5, 6.5.6	Discuss key assumptions and rate and yield goals that must be achieved to meet contractual delivery schedules.
Manufacturing capability for critical manufacturing processes	6.2.2, 6.5.3, 6.5.4, 6.5.5	Discuss the approach for identifying key characteristics and critical manufacturing processes and developing process control plans. Provide a listing of anticipated critical manufacturing processes.

6.4.1 Supply Chain and Material Management

6.4.1.1 Technology obsolescence and Diminishing Manufacturing Sources (DMS). Diminishing Manufacturing Sources and Material Shortages (DMSMS), the loss of sources of items or material, surfaces when a source announces the actual or impending discontinuation of a product, or when procurements fail because of product unavailability. DMSMS may endanger the life-cycle support and viability of the weapon system or equipment.

6.4.1.2 Problem defined. Compared with the commercial electronics sector, the DoD is a minor consumer of electrical and electronic devices. The DoD is continuously seeking to prolong the life of its weapon systems. These trends cause DMSMS problems as repair parts or materials disappear before the end of the weapon system life cycle. While electronics are most likely to be discontinued, obsolescence of non-electronic and commercial off-the-shelf (COTS) items also poses a significant problem to weapon systems. In short, DMSMS is a threat to system supportability. The impact of technology obsolescence and diminishing manufacturing sources on the cost and performance of our Weapon Systems has increased significantly over the last ten years. This is due to the

accelerated rate of technology change (especially in electronics), our growing dependence on commercial sources, and the relatively long development time and operational life of our systems.

6.4.1.3 Guidance. Solving DMSMS is complex, data intensive, and expensive process. There are basically only two approaches to solving DMSMS in a system: reactive (address DMSMS problems after they surface) and proactive (identify and take steps to mitigate impending DMSMS problems before programmatic impact). DoD policy prescribes the proactive approach. An effective DMSMS program does the following:

a. Ensures that all parts and material to produce or repair the system are available

b. Reduces, or controls, total ownership cost (TOC)

c. Minimizes total life-cycle systems management (TLCSM) cost

d. Eliminates, or at least minimizes, reactive DMSMS actions

e. Evaluates design alternatives

f. Provides for risk mitigation as it applies to DMSMS

g. Evaluates more than one approach to resolve DMSMS issues

h. Collects metrics to monitor program effectiveness.

6.4.1.4 Importance of an accurate BOM. It is critical to recognize the importance of an accurate Bill Of Material (BOM) in creating a proactive DMSMS program. The BOM is the indispensable data resource that enables proactive DMSMS management. Without it, impact analysis, component analysis, prediction of discontinuance, and other DMSMS-related activities would not be possible. A BOM is a list of parts and materials (electronic, electrical, mechanical, and so on) needed to produce a system or assembly. An indentured BOM shows the relationship (generally in a top-down breakout format) of components to board, to box, and to system. Ideally, the BOM should be in an editable electronic open-standards-based format. Common sense dictates that the level of DMSMS management practice cannot possibly be the same for every weapon system and therefore it cannot be one size fits all. Programs are encouraged to discuss this matter with their contractors, suppliers and Subject Matter Experts (SME) within DoD to develop a viable effective approach for their respective programs.

6.4.1.5 Lessons learned. In some cases, commercial demand for materials or components that have historically been used only in defense systems can nearly push DoD out of the market. Two examples are Graphite Carbon Fiber composites used in low observable airframe manufacturing and Liquid Crystal Displays (LCDs) used in avionics components

a. The demand for graphite for the sport and entertainment industry (e.g. golf clubs and tennis racquets) stretched lead times until additional production facilities came on line to accommodate the increased demand. The best strategy in this case was early anticipation of military and commercial needs for graphite making it possible to lock up production capacity options with the main suppliers in advance.

b. The explosion in the personal communication and gaming industry (e.g. cell phones and electronic game systems) made it nearly impossible to interest manufacturers of LCDs in a production run of a few hundred for a new fighter program when commercial demands for quantities in the millions were waiting. The best strategy in this case has been cooperation in development of new components across different platforms, and even across services, wherever possible. Rather than demanding a different LCD for the program A, program B and program C when the function they serve is basically the same, we need to agree on a common component…a design as close to commercial equivalents as possible. The combined demand for this common component is more attractive to potential producers.

6.4.1.6 Counterfeit part prevention. According to the General Accountability Office (GAO), the increase in counterfeit parts is one of several potential barriers the DoD faces in addressing part quality problems. They further acknowledge that counterfeit parts have the potential to seriously disrupt DoD's supply chain, delay missions, affect the integrity of weapon systems, and ultimately endanger the lives of our troops. Traditionally supply chains are critical parts of larger enterprise. Attention must be paid to all things coming into that enterprise that could someday affect the enterprise in an adverse manner and introduce vulnerabilities. As the DoD draws from a large network of suppliers in an increasingly global supply chain, there can be limited visibility into these sources and greater risk of procuring counterfeit parts.

6.4.1.7 Incentives for counterfeiting. Profit is the primary incentive for counterfeiting. However, there are unique conditions that make aerospace and defense products susceptible to counterfeiting, including a long life cycle and Diminishing Manufacturing Sources and Material Shortages (DMSMS) issues. Aerospace and defense products are generally designed for a long life cycle. For example; The B-52 went into service in February 1955 and currently has an anticipated retirement date of 2040. Therefore, supporting aerospace and defense products throughout their lifecycle sometimes requires the use of parts that may no longer be available from the Original Equipment Manufacturer (OEM), authorized aftermarket manufacturer or through franchised or authorized distributors or resellers. When parts and materials, such as microcircuits, are acquired through distribution channels other than those franchised or authorized by the original manufacturer, there is the potential to receive parts that do not meet the original specifications.

6.4.1.8 Guidance. A comprehensive counterfeit parts program must address, as a minimum, the following topics:

a. requirements

b. prevention

c. detection

d. reporting.

6.4.1.9 Requirements. Effective contractual requirements are critical to focusing a program's prime contractor to take the proper course of action. Develop requirement inputs to Requests for Proposals (RFPs) and Statements of Work/Statements of Objectives (SOW/SOO) An example for a SOW input focusing on counterfeit part prevention follows.

Example: The "contractor" shall develop and implement a Counterfeit Parts Prevention (CPP) Program in compliance with SAE AS5553 to prevent the inclusion of counterfeit parts or parts imbedded with malicious logic into products intended for sale to the government. As part of CPP, the contractor shall provide Certificates of Conformance (CoC) as well as acquisition traceability for Original Component Manufacturers (OCMs) and franchised/distributors in the supply chain, for example Certificates of Conformance and Traceability (CoCT). As an alternative to a stand-alone CPP, the elements of DI-MISC-81832 may be included in the Program Protection Plan (PPP).

6.4.1.10 Prevention. Potential preventative actions are listed below.

a. Government and contractors should make sure all parts are procured directly from OEMs/OCMs and authorized distributors, rather than parts brokers, independent distributors, or the gray market. Contractors should make sure government program managers are notified when the parts are not obtained from the OEM and/or authorized distributors.

b. Primes should specify flow down of applicable requirements to include AS5553 to lower tier suppliers and maintain processes to verify such requirement.

c. Contractors should use robust quality management systems (for example, AS9100 for equipment providers and AS9120 for distributors).

d. Contractors should conduct surveys of their suppliers' inspection and testing capabilities and audit their counterfeit prevention program.

e. Traceability is a key means for verifying legitimate parts in any supply channel. Organizations should require their suppliers to trace parts back to OEMs/OCMs in order to prove part authenticity.

f. All requirements should be communicated to an organization's suppliers instead of assuming that suppliers take unilateral actions to prevent counterfeits.

g. The government should benchmark other companies and suppliers and pool information on anti-counterfeiting strategies. Contractors should benchmark and share best practices within their own supply chain.

h. Contractors should maintain a register of approved suppliers, including the scope of the approval, to minimize the risk of counterfeit parts supply.

6.4.1.11 Detection. Potential detection actions are listed below.

a. Primes and suppliers should conduct training in Counterfeit Parts Avoidance for Inspectors, Operators, Auditors, and lower tier suppliers to include awareness of AS5553. Training should discuss how to inspect parts and identify possible counterfeits (for example, non-conforming part markings).

b. Primes and suppliers should institute strong incoming quality assurance on all parts and visually inspect. Paperwork is not a substitute for testing.

c. Prime contractors should require certificates of conformance, testing certification, and procedures for handling any counterfeit parts that slip through the system.

d. Processes should specify methods for physical identification, segregation/quarantine, and control of suspect or confirmed counterfeit parts to preclude their use or installation. These processes should ensure the counterfeit parts do not re-enter the supply chain.

e. The documented processes should ensure detection of counterfeit parts prior to formal product acceptance.

f. Contractors should assess potential sources of supply (electronic parts, assemblies, and equipment suppliers) to determine the risk of receiving counterfeit parts. Assessment actions may include surveys, audits, review of product alerts (for example, GIDEP, ERAI), and review of supplier quality data to determine past performance.

g. If items are confirmed to be counterfeit, contractors should not return the part to the actual or potential supplier at any time prior to criminal authorities' release of disposition.

6.4.1.12 Reporting. Potential reporting actions are listed below.

a. Reporting processes should ensure all occurrences of counterfeit parts are reported to internal organizations, customers, government reporting organizations (for example, GIDEP), industry supported reporting programs (for example, ERAI), and criminal investigative authorities.

b. When contractors are notified by their suppliers regarding a potential suspect or a confirmed counterfeit part, they should notify the program offices as soon as possible (within 30 days of the original notification).

c. Suspected counterfeit material should be submitted, analyzed, and a resolution determination should be made using the Joint Deficiency Reporting System (JDRS) Additional information about JDRS can be found at www.jdrs.mil.

6.4.2 Manufacturing technology development. Program offices should work with their respective service's research lab for assistance with technology expertise, project management, and funding. The Manufacturing Readiness Levels of new technologies should be assessed to minimize transition to production risks.

6.4.3 Cost. Cost realism and credibility are primary concerns in a budget-constrained environment. Early, frequent, and increasingly accurate Production Cost Modeling (PCM) becomes extremely important. The PCM must be continuously refined as the design definition improves and should be used to estimate the projected production cost of the proposed design against a threshold value for affordability. The PCM addresses all design driven cost elements and be updated to stay current with the evolving product design and production plans. The PCM plays a key role in assessing the overall progress of the development program. Current cost estimates at major milestones, plus the status of current and planned cost risk abatement efforts, help determine whether to proceed to the next phase. The model has three major attributes:

1. ability to be used in design trades to assess the cost impacts of specific design changes, alternative production processes or process improvements.

2. ability to incorporate the most recent actual manufacturing costs into the production cost estimate.

3. ability to support finance and contracting processes (such as independent program estimates, proposal preparation, fact-finding & negotiations, budgeting, and what-ifs).

6.4.3.1 Guidance. The intent of PCM is to provide a tool for predicting and controlling design driven production costs. The PCM should also predict the production cost impacts of production rate and delivery schedule variations that are sure to occur in every program.

6.4.3.2 Define specific parameters. For the contractor to develop a valid cost model, the government must define specific parameters in early development. These include variables such as constant versus then year dollars, production quantities and rates, and any fiscal year budget constraints. The production quantities and rates are important in defining the return on investment for capital equipment costs and other cost reduction initiatives that have a strong influence on product design. To avoid a "point" design solution, the production rates and volumes may be defined as ranges with the target rate identified. With few exceptions, these assumptions have a significant impact on the final design and production cost. The assumptions must be as realistic as possible and the rate/volume ranges as narrow as possible.

6.4.3.3 Analysis procedure selection. Any appropriate analysis procedure may be used in developing the PCM (parametric, historical, analogy, or detailed engineering estimates) depending on data availability and the maturity of candidate designs. In most cases, it will be important to account for Special Tooling (ST), Special Test Equipment (STE), Support Equipment (SE), Government Furnished Property (GFP), sustaining engineering and rate tooling in the estimate. The PCM should include factors that account for inspection, test, scrap, and rework. Many commercial cost models are available for use and/or adaptation to fit company-unique accounting systems. The level of detail and the complexity of the cost models appropriate for a product will vary depending on the product's complexity, the program phase, size, and other related factors.

6.4.3.4 Modeling production costs. Accurately modeling production costs early in development is virtually impossible and there will always be an uncertainty interval associated with the resulting estimate. This uncertainty interval will be relatively large early in the development phase, but should continuously shrink as the design and process capabilities solidify. This is because inputs to the PCM will be initially calculated with the limited fidelity of Rough Orders of Magnitude (ROM) estimates or with parametric data. The PCM should be refined as the detailed design and manufacturing plans are developed

6.4.3.5 Development and maintenance of the PCM is a team effort. The contractor and the government should make the development and maintenance of the PCM a joint goal. Each group should work together to define the overall architecture, input requirements, ground rules & assumptions, levels of detail to be included, and output formats. Over time, organizations have approached this from two extremes, some with the contractor exercising total ownership over the model, others with both the contractor and government each running their own independent models. A single model, jointly agreed upon, provides the best path and engenders a close, teaming relationship. It also gives both the government and contractor a common understanding and language with which to evaluate potential design and programmatic changes. It also facilitates contracting processes, such as negotiations of yearly lot buys.

6.4.3.6 Lessons learned. Start early looking for cost reductions. Studies have repeatedly shown the best opportunities for system cost reduction occur during early program development phases. The early initiation of PCM supports cost reduction activities by helping to identify the areas with the greatest potential for payback. Previous experience with Design to Cost (DTC) approaches has been disappointing. It can be erroneously applied as an “accounting afterthought” by merely booking changes to the cost estimate as opposed to providing direction on where to focus cost reduction activities. Also, in many cases, the ground rules and assumptions that fed production cost models (rate, volume, and schedule) were not updated to reflect program changes and so the production cost estimates produced by the DTC activities had no validity.

6.4.3.7 Maintain PCM. To be effective and credible, the PCM must be maintained and kept current with all program ground rules and assumptions. Configuration control of joint PCM models must be explicitly documented. Specifically, both sides must agree on how changes are to be made and how disputes are to be handled.

6.4.4 Manufacturing Modeling and Simulation (M&S) M&S addresses the properties and interactions among the materials, production processes, tooling, facilities, and personnel involved in a new product’s design and manufacture before the product and process designs are released. The goal is to impact producibility while changes can still be made in a cost effective manner. In traditional product development approaches, by contrast, decisions made during initial development phases have often locked 65% to 75% of the cost into the product, and have proven difficult or extremely expensive to change once tooling is built and production has begun. Ideally, M&S is used very early in development to evaluate the producibility and affordability of proposed design concepts,

and continues to be used and refined providing ever increasing fidelity as the system design evolves.

6.4.4.1 Manufacturing cost. The cost associated with manufacturing generally decreases over time due to ongoing improvements in production methods and the experience gained by the workforce as they repeat assembly tasks. M&S accelerates this improvement by allowing some of the anticipated methods improvement to occur before the first unit is assembled. Virtual tools let the producer begin production at a lower T1 cost, in effect, skipping much of the inefficiency common early in production.

6.4.4.2 Simulations. Simulations can also be used to model new factory designs, such as during a Value Stream Analysis exercise. The planned version of the factory can be analyzed in a virtual environment for capacity, flow, transportation times, and other parameters, prior to being implemented. The design can be modified as needed before physical changes are made to the facility. The transition to the planned factory may take a significant amount of time and the simulation can be used to validate progress along the way.

6.4.4.3 Product design. Product design largely consists of repeated iterations of simple design-build-test-analyze cycles. Historically the build part of these cycles included construction of physical mock-ups. While these physical mock-ups allowed for visualization of the product and rehearsing of some build processes, they took a lot of time and money to build, were cumbersome, difficult to modify, and they took up a lot of floor space. Iterations in an M&S environment are often possible at a much lower cost and on significantly more accelerated schedules than in a physical environment. The result is greater insight into the effect of design changes at each stage, and the ability to quickly iterate the design development to approach an optimum solution in less time.

6.4.4.4 Benefits of M&S. Using the electronic product model with various simulation tools also gives the producer the ability to extend the utility of M&S to include optimization of the factory production process. By simulating various factory layouts and flows, the entire development process can be optimized and shortened. So, virtual tools hold great potential for reversing current trends toward longer and longer development cycles. Like line proofing, M&S supports risk management activities by verifying and validating the capabilities of the production facilities. Unlike line proofing, M&S does not require actual production tooling and a first set of parts since it builds virtual rather than actual products or product components. Manufacturing simulation tools like Variation Simulation Analysis (VSA) are used to identify sources of variation in the production processes and to predict production yields. By simulating the production of 100 or more parts to a specified design tolerance given known production limitations, production yields can be accurately predicted early in the design process, months before metal is machined and hardware is produced. In this way, the designer can identify limitations to the producibility of the design early in the development process, when it can be fixed at a lower cost.

6.4.4.5 Prototyping tools. Stereo Lithography Apparatus (SLA) and Selective Laser Sintering (SLS) have long been rapid prototyping tools that provide sub-scale or full-scale physical models directly from CAD designs. 3D Printing and Additive

Manufacturing extend the same principles but include an ever increasing array of material options to produce working production parts instead of models. While current capabilities are still limited to a very specific grouping of parts (like circuit boards and non-load bearing structural and mechanical components) 3D Printing is widely seen as the future of manufacturing.

6.4.4.6 Guidance. Virtual manufacturing simulations should be integrated with CAD tools, MRP, scheduling tools, time standards, work instructions, and planning. Virtual tools can address different levels of manufacturing processes, including:

a. yield modeling: These models are used in the electronics fabrication industry to predict first pass yields based on key design and process attributes. Once a baseline process is characterized, process yields can then be predicted for new or changed designs.

b. manufacturing ergonomics modeling: These models focus on individual assembly processes and include computer mock-ups of parts and processes to help ensure human factors considerations are taken into account.

c. production line modeling: These models can vary from hand-drawn value stream maps to off-the-shelf factory simulation software (for example, Java® based AnyLogic®, Simio ®, Arena®, or equal). These models often address material movement, processing times, and scrap, rework and repair levels to ensure that production delivery rates can be achieved.

d. supply chain modeling: The most common supply chain models focus on supplier delivery rates and inventory levels. However, more complex factors could be considered, such as impacts of disruptions, supplier capabilities and yields, learning curve effects, obsolescence issues.

e. value stream mapping: The value stream map is a conceptual flow diagram which shows the process for creating a product from raw material all the way to the customer. It should be complete with all types of information, material, parts, and physical processing times and physical movements as well as any queues that build into the system. Once the current state of the facility is accurately modeled, it’s time for the team to go to work on evaluating where improvements can be made.

6.4.4.7 Lessons learned. The ability to assess manufacturing capabilities in a synthetic environment early in the design process has contributed to lower total costs, reduced technical and schedule risk in the transition to production, and increased confidence that programs can meet affordability targets. The effectiveness of the early implementation of M&S was demonstrated on a major commercial aircraft program, which reported a 90% reduction in error related changes after the release of the product design. A program to redesign an existing bulkhead on a major aircraft program demonstrated the benefits of M&S by comparing results to those of parallel activities without M&S. The design cycle time was reduced by 33%, and design cost was reduced by 27%. Another program used solid modeling, parametric design, and M&S tools to redesign a tail stabilizer on a major trainer aircraft program. EMD phase savings of 28% were achieved in comparison to the lower of two competitive bids using conventional design approaches.

6.4.4.8 Develop data beyond preliminary design. A basic type simulation allowed a major engine program to correct a supply chain issue at a vendor which was being blamed for late deliveries and capacity issues. The simulation pointed to delivery of material from the prime contractor to the supplier as the cause of production flow problems. Modeling and simulation would be effective at analyzing surge capability for individual factories and the supply chain.

6.4.5 Manufacturing System Verification. Refer to Section 6.5.6 Production process verification for detailed information about manufacturing system verification and how it relates to similar activities.

6.4.6 Manufacturing Workforce. The contractor's anticipated workforce needs (both in numbers and skills) should be evaluated as part of MRL assessments and PRRs. the manpower required for a given program should be compared with projected requirements for all programs in a given facility to determine if there are future constraints that must be addressed. To assess the ability to acquire skilled workers, consider the types of local industries, the competitiveness of the labor market, and the availability of technical and higher education.

6.4.7 Tooling / test equipment / facilities. Tooling and test equipment can be major cost and risk drivers and must be addressed in the considerations of alternatives. If new/unique tooling and/or test equipment is required, the program office will need to manage its design, development, fabrication, qualification, and maintenance throughout the development and production phases.

6.4.7.1 Establishment of tooling and test equipment. Programs need to establish their tooling and test equipment concepts and determine if they need to develop new/unique tooling and test equipment early in product development. If new/unique tooling and test equipment are needed, the risk this presents in achieving program requirements and objectives must be addressed early. An assessment of new/unique tooling and test equipment will be required to evaluate the various producibility alternatives being considered and to understand the overall requirements of tooling and test equipment and how it will impact the cost. This information can be used to understand the cost and performance risk in selecting the best tooling and producibility alternatives and to begin risk planning to address the potential risks.

6.4.7.2 Equipment use. Once the tooling and test equipment requirements are established, the equipment should be built and used as early as possible in a production representative or pilot line environment. The rate capability and yield rates of EMD tooling and test equipment must be evaluated to ensure there is adequate capacity to proceed into production. The contractor should conduct capacity analyses to determine the number of tools and test sets needed for both Low Rate Initial Production (LRIP) and Full Rate Production (FRP). The capability and capacity estimates should include key elements such as cycle time, yield, scrap and rework, etc. The underlying rate and yield assumptions should be monitored during EMD and early LRIP lots to ensure the assumptions made during the capacity analyses are being met. Preventive maintenance procedures should also be developed and verified at this time.

6.4.7.3 Program manager role. Program managers must plan for the preservation and storage of special tooling, which includes jigs, dies, fixtures, molds, patterns, taps, and gages which are of such a specialized nature that without modification or alteration their use is limited to the development or production of particular supplies or parts. Special tooling must be serially managed using part numbers, serial numbers, unique item identifiers, and/or national stock numbers. Planning for the preservation of special tooling must include the methods of preservation and packaging, storage standards, storage location, inspection requirements, and the contracts and budgets to execute the preservation and storage. Program managers should collaborate with their industry counterparts and DCMA to establish an efficient process for dispositioning unnecessary and/or obsolete tooling and test equipment throughout the program lifecycle. Program managers should also plan for the end of production, in advance of need, by

a. identifying tooling and test equipment that will be necessary for ongoing operational/logistics support efforts, and

b. planning for an orderly production line shutdown that minimizes plant disruption, “exits” production within budgetary constraints, and preserves, to the greatest extent practicable, flexibility in support of post-production activities (e.g., production line re-start or ongoing spares production).

6.5 Manufacturing operations management

6.5.1 Production scheduling and control. To obtain insight into a contractor’s production control system, a program office may request on-line access to the contractor’s system or, as a minimum, to any metrics generated by the system. As an independent schedule assessment, the program office may also wish to create a Line of Balance (LOB) metric to track build progress and predict future delivery performance. As defined in AS6500, LOB is a production control technique that combines features from a critical path scheduling timeline with a required delivery schedule that is presented in graphic form. It shows the delivery objective, the sequence and duration of all activities required to produce a product, the current status of production items, and an assessment showing the relationship of actual component production to schedule. The knowledge of the critical path of production is essential knowledge for managing manufacturing operations. Lean efforts and other optimization initiatives should primarily be focused on critical path operations; otherwise, a reduction in span time may have little or no overall effect on the overall schedule performance. The type of production scheduling used by the contractor can have a significant effect on schedule performance and manufacturing efficiency. There are two primary approaches:

a. A push system is typically governed by an automated scheduling program that directs that product be produced at a station and then moved to the next station based on anticipated task durations for station. Push systems can cause overproduction and a build-up of unnecessary inventory

b. A pull system only tells a previous station to produce product when it is needed and may rely on Kanban cards to communicate throughout the factory. Pull systems are preferred approaches in lean manufacturing operations.

6.5.2 Manufacturing Surveillance

6.5.2.1 Factory performance data. In the current acquisition environment, submission of factory performance data is usually not a contractual requirement. Not having insight into this data, however, means blinding the government to a contractor's real ability to perform to a contract delivery schedule. Lack of data degrades a program office's ability to respond to "What-If" scenarios and to independently assess a contractor's recovery schedule. The government and contractor team should develop an agreement of what data will be informally provided to the government. The data can be in the contractor's format to avoid the additional expense of converting the data. Some contractors provide the government online access directly to their databases and metrics. Data that should be provided include:

a. Summary Production Schedule.

b. Labor Performance Data (actual hours versus work measurement standards).

c. Line of Balance (or similar status) charts.

d. Scrap, Rework and Repair metrics (Cost of Quality metrics should be pursued in addition to Scrap, Rework and Repair; additional information can be found in 6.5.9.4).

e. Supplier schedules and status.

6.5.3 Continuous Improvement

. A key element of continuous improvement is the elimination of waste. Waste can come from overproduction, waiting time, transportation, processing, inventory, excess motion, and product defects. The following ideas and tools should be considered to eliminate these wastes and to implement a world-class, lean manufacturing operation:

a. Continuous or Single Piece process flow – production part movements based on a principle of Lean Manufacturing that breaks the production line into a sequence of short duration, perfectly synchronized tasks which minimize delay, wasted effort, and in-process inventory.

b. Just-in-time manufacturing and inventory systems – a resource allocation and part supply strategy (requiring a predictable well timed production process) where the delivery of production parts, tools and other resources occur exactly when (or very shortly before) they are needed.

c. Pull systems – a production control and synchronization approach designed to facilitate small lot sizes and ultimately single piece flow by limiting in-process inventory, bringing the next work piece from the previous work station only when the station is ready to receive it (often implemented with Kanban cards).

d. Empowered employee teams – an organizational strategy allocating authority and responsibility to appropriately trained employee teams (usually with cross-functional membership) for short, intense improvement efforts or long term project management.

e. Cellular manufacturing – a method for laying out production organizations in product-based cells as opposed to traditional process layouts based on common machine type, so that each business unit is a complete production organization that can be flow

analyzed and optimized. Multi-skilled operators are a key to the success of manufacturing cells.

f. Standardized Work and Kaizen events – Standardized work involves detailed, step-by-step guidelines to assure consistent processes with minimal part-to-part variability. Kaizan events are concerted, continuous improvement activities that result in improved standard work packages.

6.5.3.1 Work measurement program. To measure the progress and success in becoming more efficient, companies must select appropriate metrics. Some form of a work measurement program is needed to develop labor standards that quantify the amount of time it should take a qualified worker, with the right parts and tools, to perform a task. The work measurement program should include a data collection system to then measure the actual time it took and analyze the types of inefficiencies, their root causes, and ways to improve performance. Typical metrics that are valuable for providing insight into factory efficiency include:

a. Scrap, Rework and Repair: hours or dollars as a percentage of manufacturing costs (note, however, that Cost of Quality, discussed below in 6.5.9.4 , is a better metric for driving continuous improvement efforts).

b. Realization Factors: the actual time to perform a task divided by the engineered labor standard. Metrics should include a breakout of the elements of realization, such as operator learning, quality problems, waiting time, engineering errors, machine downtime, etc. Some companies track this as “efficiency” which is calculated by dividing the standards by the actuals (the inverse of realization.)

6.5.3.2 Lessons learned. Many companies fall into two common traps. The first is to (correctly) “prototype” the implementation of lean in a limited area or production cell. However, even though the area may show tremendous improvement, the company does not follow through with the institutionalization of Lean across the rest of the factory. The second trap is to conduct a single Kaizan event in a given area and claim success. The Toyota Production System emphasizes continual improvement and the conduct of Kaizan events periodically in the same area. There are always opportunities to improve – they are never exhausted. Creation of innovative financial incentives may be required to encourage all team members to embrace the long-term benefits of Lean over short-term profits. Tools such as Award Fees, incentives tied to target price curves, or even a separate pool of money dedicated to efficiency investments have been helpful on some programs.

6.5.4 Process control plans. Variability Reduction (VR) is a systematic approach to improve product performance, reliability, cost, and reduce manufacturing span times by reducing variation in key product characteristics and the processes that create them. It is based on a well-known quality management principle: the focus on processes, continuous improvement, and the use of data and facts to make decisions. VR efforts during development are intended to lay the foundation for continuous improvement in product quality during the production phase. VR activities that should be undertaken in development are:

a. develop control plans for critical processes

b. begin data collection on key processes to determine process capabilities

c. feed these process capabilities back to the designers

d. implement improvements in design standards and/or the design process, and

e. implement improvements in the design and/or manufacturing processes, as required.

6.5.4.1 Data analysis. As development progresses and developmental units are being built, more process data becomes available. This data must first be analyzed for applicability, given potential design and process changes. When the data is deemed acceptable, it can be used to gain an initial understanding of the process capabilities. This process capability information should be fed back to the design engineers, forming what is sometimes called a closed-loop design process.

6.5.4.2 Process improvement. Production phase variability reduction (VR) efforts are primarily concerned with addressing capability shortfalls with special variability reduction efforts, and maintaining an environment of continuous improvement in product and process quality. During the production phase, process capability and product quality should continue to improve even after the baseline program requirements have been achieved. The team should strive to achieve process stability for all critical processes and to continually improve process capabilities where capability improvement will result in a better product at a reduced cost. VR activities that should be undertaken in production are:

a. data collection during production operations to monitor process performance and initiate preventive actions

b. use of process improvements during build activities

c. assessment of feedback received from field users and support personnel, and field reliability data, and

d. use of design enhancements to improve performance, producibility, and affordability.

6.5.4.3 Conclusion. VR is based on the concept that simply attaining specification limits (also known as a “goal-post mentality”) is not the best measure of quality. Rather, the degree of variability inherent in a key process and its relationship to design limits (process capability) becomes a measure of merit. According to FIGURE 5, any deviation of one of a product’s principle functional characteristics from nominal results in a loss to society. For defense acquisition programs, this loss to society can be defined in terms of performance degradations, increases in life cycle costs, or both. The larger the deviation from nominal, the higher the loss. Therefore, the logical solution is to reduce the amount of variability by centering the process output as tightly as possible on the nominal specification value.

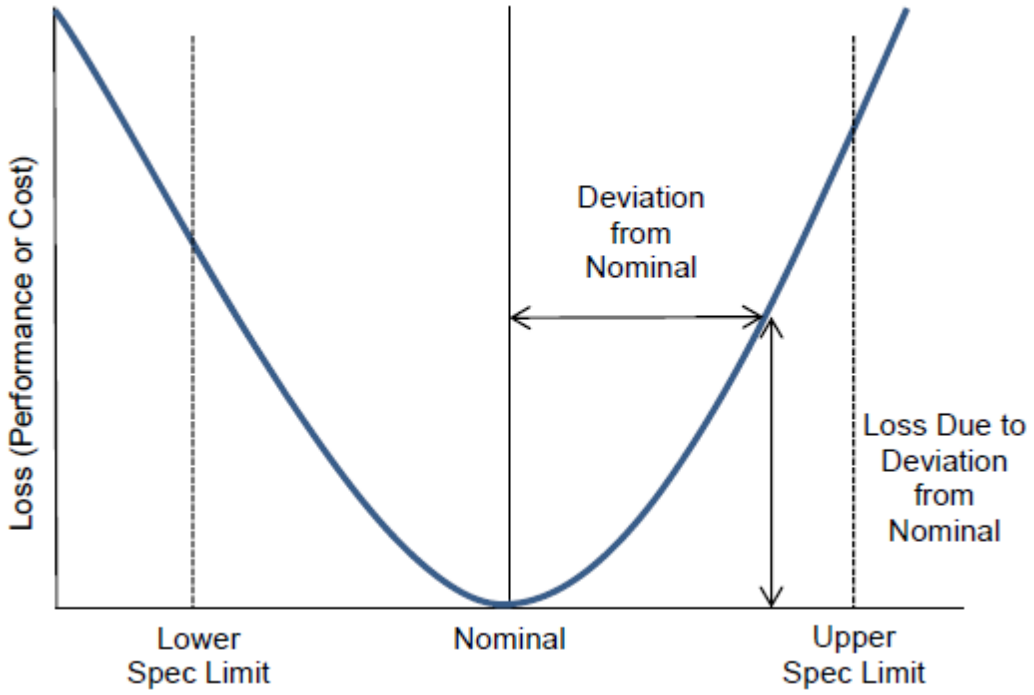

FIGURE 5. Taguchi Loss Function.

6.5.4.4 Benefits. By reducing and controlling hardware variability, the customers and suppliers can realize many benefits, including:

a. Quality improvement in the form of better fit, performance, and reliability

b. Cost savings from reduced assembly hours

c. Cost reduction due to reduced scrap, rework, and repair

d. Better design decisions made possible by the engineer's knowledge of the factory's process capabilities resulting in less design rework, lower development cost, and shorter lead times

e. Reduced reliance on end-item inspections to detect nonconformance resulting in reduced inspection cost

f. Customer satisfaction due to increased service life

6.5.4.5 Guidance. FIGURE 6 shows the sequence of activities for a Variability Reduction Program.

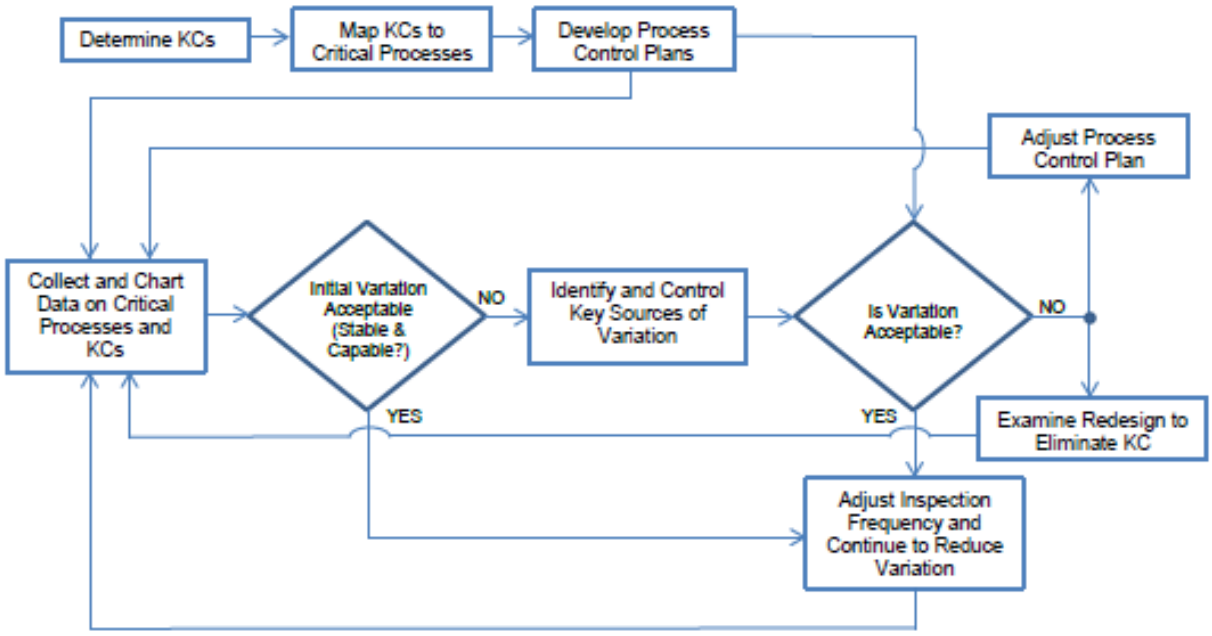

FIGURE 6. VR general approach.

6.5.4.6 Determine KCs. Two aspects of variability reduction affect the design of characteristics that have been identified as key.

a. Initial design tolerances should reflect process capability limitations. Data from similar parts and processes can be used to give designers guidance on the tolerances they can reasonably expect the manufacturing organization to consistently attain without significant improvements to production processes and equipment. This process capability data may be collected with automated tools, and is often recorded in databases or design handbooks.

b. If indications are that manufacturing cannot reliably reproduce a proposed KC, the designers should try to eliminate that feature or, at a minimum, make it more robust and less sensitive to variation. These design modifications are nearly always less expensive than the two alternatives: upgrading the factory or accepting the cost of poor quality.

6.5.4.7 Develop process control plans. For each critical process related to a KC, the contractor should document plans to control the process to ensure KC variation is, at a minimum, within spec, and as a goal, reduced as much as feasible. These process plans may cover multiple KCs, since a single process may produce more than one key characteristic. The method and frequency of documentation depends on the complexity of the characteristic and the process. The control plan should always include a brief explanation of the KC, what data will be collected, where in the process it will be collected, how it will be collected, and how it will be analyzed (types of charting and who will analyze it). Additional content will vary with the type of key characteristic. Traditional Statistical Process Control charting is not necessarily required for all KCs, but it is highly encouraged. As a minimum, some data must be collected to determine and document product conformance. Process control plans should also address the

measurement system and its ability to accurately ensure product conformance to specifications. Process control plans should be considered dynamic and the IPT should adjust them periodically to account for changes in process capability.

6.5.4.8 Collect and chart data. Data should be collected in accordance with the process control plan. Early in development when few items are produced, short-run techniques must be used to analyze data to make statistically significant observations. One option is to use data from other products produced using the same process. Numerous industry sources are available to assist in the collection and analysis of limited data.

6.5.4.9 Initial variation acceptability. To determine acceptability, you must calculate the process capability index (Cpk), following the guidance in 6.5.5 Process capabilities.

6.5.4.10 Adjust inspection frequency. If process variation is acceptable, inspections may be reduced. Once the process has demonstrated capability and control, certified operators may be allowed to rely on Statistical Process Control (SPC) charting to monitor and accept products and to ensure that no major shifts in the process occur. The quality organization may need only audit the SPC data collection process and/or sample the final product to ensure the process control plans are effective.

6.5.4.11 Identify and control key sources of variation. If initial variation is not acceptable, the team must identify the sources of variation, both the common and special causes. Special cause variation is variation that is not inherent to a process, is due to some outside (often controllable) influence, and is usually detected by its predictable, nonrandom frequency. For example, it may include variation introduced by tooling, machine programming, or drill bit wear. These special causes must first be removed to determine the true expected output of the process. The remaining variation is termed common cause variation and results from causes inherent to the process. Its frequency of occurrence is unpredictable and random. These cannot usually be eliminated without a major change to the process (such as by the installation of humidity controls in a humid environment).

6.5.4.12 Understand the process. Whether variation in a process is special cause or common, it is necessary to gain a complete understanding of the process itself in order to identify and control sources of variation. For this reason, many variability reduction methodologies include process flowcharting and a detailed analysis of inputs, outputs, and controls for each process step. The flowchart, and the detailed data associated with it, serves as a starting point for identifying and controlling sources of special cause variation.

6.5.4.13 Variation acceptability. If the variation is still not acceptable after special causes have been eliminated and common causes controlled to the extent possible, other actions must be taken. In some cases, it might not be economically feasible to reduce variation by changing the production process. The following are some options:

6.5.4.14 Examine redesign to eliminate KC. The preferred option is to redesign the product to eliminate the sensitivity of the design to the key characteristic; the characteristic may still exist, but the design is more robust so that it is no longer critical.

Another option, if performance allows, is to open the design tolerances on the characteristic. By definition, this will improve the Process Capability Index (Cpk). In design development, tolerances should be set as wide as possible. These tolerances should be loosened later in production only if it is determined that they were too tight to begin with, or something has changed in the design of the system to make the initial tolerances unnecessary. This action may also require changes to interfacing parts or relaxation of requirements.

6.5.4.15 Adjust process control plan. If process variation is still not acceptable, additional controls (such as inspection) may be added to ensure that only conforming product is delivered to the next step in the process. However, many years of experience with inspection have shown that it is not a perfect solution. Most inspection is still performed by humans, who have a limited capability. Even if every item is inspected, there is still a probability that some nonconforming product will be accepted. The use of go/no-go gauges is an industry preferred method to simplify inspections and enable inspectors to be more successful.

6.5.4.16 Additional guidance. One method of contractually implementing KCs and VR is to include AS9103 in the SOW.

6.5.4.17 Measurement Systems Analysis. Since data and decision making go hand-in-hand, the quality of the measurements from which the data is derived is very important. Factors like measurement selection, calibration, and gage repeatability and reproducibility directly influence the process output and should be evaluated as part of the overall process capability and control planning. A Measurement Systems Analysis evaluates the test method, measuring instruments, and the entire measurement process to ensure the integrity of the data used for analysis and to understand the implications of measurement error on decisions made about a product or process.

6.5.4.18 Additional guidance. Additional guidance on Measurement System Analysis, which is a significant part of variability reduction, and can be obtained in Section 8 of AS9100, ASTM E2783, and the AIAG Measurement Systems Analysis Manual.

6.5.4.19 Lessons learned. It is easy to lose the focus on processes and instead focus on product. Since key characteristics are naturally product related, there is a tendency to gather data on a part number by part number basis, losing sight of the fact that similar KCs on different parts may have been created with the same process. Metrics can be an extremely contentious issue. First, it is difficult to distill down a voluminous amount of complex data into a simple, easily understood chart. VR metrics can also be easily misinterpreted by those not familiar with statistical terms. For example, if a process is reported as “statistically not capable,” it may have a Cpk slightly under 1.0, but can still have a yield of nearly 99%. Additional process controls may also be in place to ensure conforming product. However, metrics are extremely important to assess the overall progress towards achieving process maturity and capability.

6.5.4.20 Measure success by results. Although there are almost as many ways to do Variability Reduction as there are contractors and subcontractors, the principles of

each methodology should begin with the goal of reducing quality costs and the philosophy of continuous improvement. Rigidly applying a methodology and generating and displaying SPC charts without a good understanding of the nature of the variability being controlled will be less than successful. For this reason, question anyone who wants to prove their Variability Reduction program is successful by showing a stack of charts. The true measure of success is results (fewer rejects, lower cost) and the only way to attain this is to understand the production process.

6.5.4.21 SPC short run application. Some manufacturers in DoD avoid using SPC because of low quantities and the belief that it is only applicable to large production runs. However, there are many short run SPC techniques developed by commercial organizations. In some products, there may be processes that are repeated hundreds or thousands of times, such as hole drilling, that would lend themselves to SPC. In addition, multiple measurements can be taken from a single part, such as with deviations from nominal of an outer mold line on a machined part.

6.5.4.22 Use understood data. The statistical analysis of production data has been facilitated by many time and labor saving devices developed over the last few years. Most are in the form of computer software and automated gauges that do the necessary calculations for the operator. While these tools bring a powerful capability, they also create an opportunity for misapplication of data and confusion. Don't assume that because a computer statistical package can take some data and provide an answer, that it is the right answer. There is one statistical principle that needs to be honored: Don't use data that is not understood (Where did it come from? Is it normally distributed?).

6.5.5 Process capabilities. The Cpk is calculated as follows:

$$Cpk = \text{Minimum } [USL-Avg,\ Avg-LSL] \ /\ 3\sigma$$

Where:

USL = Upper Specification Limit

LSL = Lower Specification Limit

Avg = Process Mean

3σ = three times the process standard deviation

NOTE: The formula above and the guidance below are based on the assumption that the characteristic has an optimum value with specification limits on either side. For cases with a one-sided tolerance (For example, within the roundness of a bearing where 0.0 out of round is optimal and there is a maximum allowable deviation from 0.0) refer to statistical texts for more detailed information regarding appropriate sampling sizes for statistically determining valid Cpks and for information on the Cp index (which is less preferred than the Cpk index).

6.5.5.1 Cpk Indications. Higher Cpk values indicate a more capable process, with a Cpk of 1.0 indicating that the process has either its upper 3-sigma variation or its lower 3-sigma variation at the specification limit (whichever is smaller), as shown on

FIGURE 7. Some companies consider a Cpk of 1.0 as “minimally capable.” A Cpk of less than 1.0 corresponds to a defect rate greater than three per thousand and it usually indicates an immature or incapable process that requires additional development, a design change, or added process verifications (such as inspections) to ensure conforming product is delivered.

6.5.5.2 Cpk Variations. While there is usually no requirement for a process to be at a certain Cpk, “AS9103 - Variation Management of Key Characteristics,” defines processes with a Cpk of greater than 1.33 to be capable. A Cpk of 2.0 is considered to be highly capable. However, acceptable variation should be considered on a case-by-case basis based on statistically sound data and considering impacts on producibility, cost, and quality considerations.

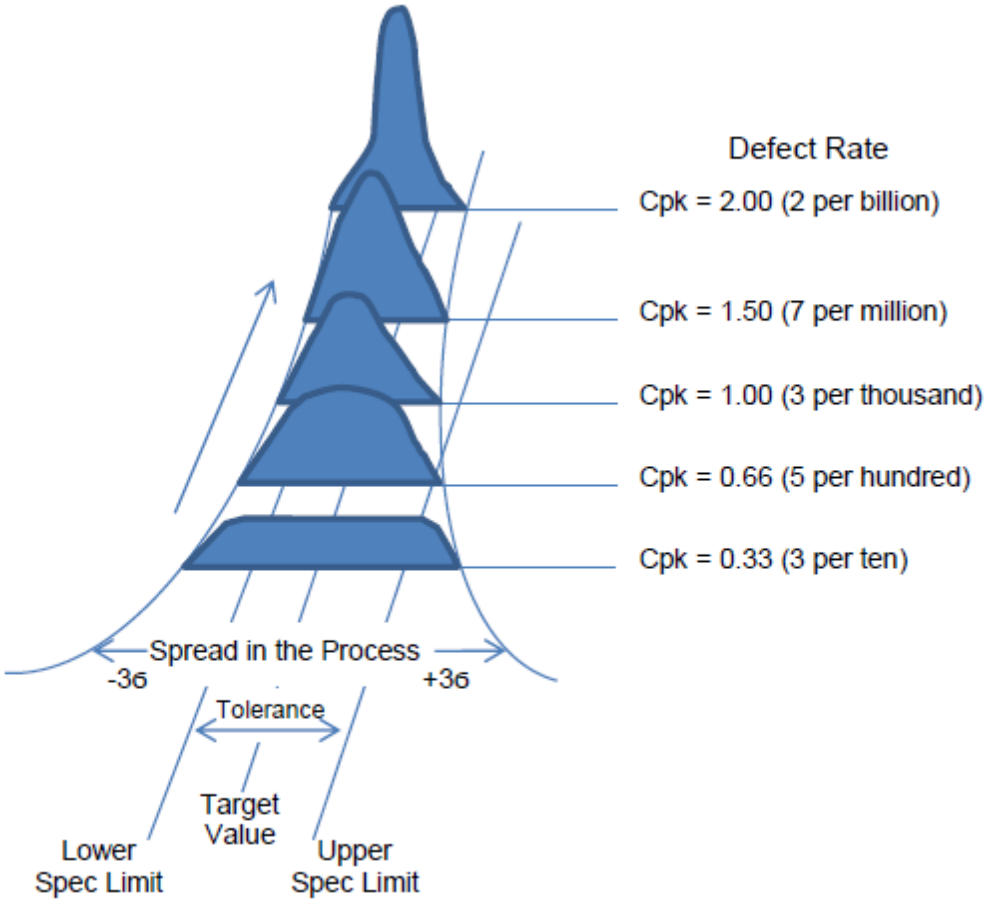

FIGURE 7. Capability index.

6.5.6 Production process verification. Today's acquisition environment emphasizes the demonstration of producibility and manufacturing capabilities at each major program milestone, beginning early in the development phase. The purpose of validation is to provide a high degree of assurance that a specific process will consistently produce a product meeting its specifications. Process validation reduces risk by evaluating

both the direct and indirect infrastructure required prior to the start of actual production articles. Product validation is used to determine if the manufacturing processes will result in a product that conforms to all contract requirements for acceptance. Product validation is usually accomplished through First Article Testing, also referred to as First Article Inspections (FAIs) and analysis of manufacturing data.

6.5.6.1 Product and process validation goals. Since quality cannot be inspected or tested into complex, finished products, the goal of the quality system is to control each step of the manufacturing process to ensure the final product meets all specification requirements. Product and process validation are key tools in determining if this goal is met. It is through careful design and validation of both the process and process controls that a manufacturer can establish a high degree of confidence that all products manufactured from successive lots will be acceptable.

6.5.6.2 Guidance. AS6500 requires several related activities that are intended to validate that production processes (including direct and indirect infrastructure) will repeatedly produce products that meet requirements including cost and schedule.

6.5.6.3 Manufacturing planning requirements. As a part of Manufacturing Planning, AS6500 requires M&S and a Manufacturing System Verification (MSV) effort. MSV is intended to be accomplished prior to production, as an analysis of the *proposed* production processes and infrastructure to determine if they are sufficient to meet requirements. If a production operation is already in place, actual data and experience from that line may be used for MSV. Since this manufacturing verification effort may be cost-prohibitive, especially for larger, more complex parts, M&S may be used to support MSV analysis.

6.5.6.4 Manufacturing Operations requirements. Within the Manufacturing Operations Management section, AS6500 requires both Production Process Verification (PPV) and First Article Inspections/Tests (FAIs/FATs). PPV is intended to be performed once actual products are being produced in a pilot line environment. Although AS9100C states PPV is often referred to as an FAI, in the context of AS6500, it has a larger purpose. The intent of PPV is to verify that the manufacturing processes are statistically capable of producing conforming parts. In other words, the purpose is similar to an MSV analysis, but PPV relies on actual data from products being produced. (MSV may only rely on M&S.) It may not be feasible to obtain enough data to be statistically significant. In those cases, thorough reviews of work instructions, process control plans, etc. along with estimates of the yields and capacities of each critical station will be needed to accomplish PPV. PPVs can also be performed on processes in place through use of coupons, samples, or similar features. For example, a plating line, or a powder coating line that is already in operation can verify the ability to produce coatings in spec for the new product about to be produced.

6.5.6.5 First Article Inspections. First Article Inspections involve a detailed inspection of a single product that was built using verified production processes. FAIs also include reviews of in-process and acceptance testing procedures and results. FAIs should include auditing the process specifications, work instructions, inspection instructions, and test procedures to ensure they consistently reflect the engineering drawing requirements.

6.5.6.6 Conclusion. AS6500 requires M&S, MSV, and PPV to verify that the production processes (including the associated infrastructure) will meet program cost, schedule, and quality requirements. AS6500 requires FAIs/FATs to verify that the specific product meets all requirements. These activities are typically performed in the following order:

M&S → MSV → PPV → FAI/FAT

Based on the scale of the program, the scope and extent of these activities (especially M&S, MSV, and PPV) should be tailored to match the program needs. Go to AS9102, for additional information on FAI.

6.5.7 First Article Inspections/First Article Tests. Since FAIs may be costly, they should not be performed on items that have significant design changes that have not yet been implemented. If only minor changes are anticipated, a full FAI may be accomplished and then a smaller, delta FAI could be done on only those features that changed. If an on-going production program begins to experience quality problems with delivered products, Hardware Quality Audits (HQAs) may be used to help “re-validate” the product and identify and correct some of the process problems. These teardown inspections are conducted on either in-process or completed production units selected at random. Like FAIs, HQAs can include an audit of the work instructions, inspection instructions, and test procedures to ensure they are still aligned with the drawing requirements. Historically, HQAs have been used with great success in identifying process quality problems.

6.5.8 Supplier Management.

6.5.8.1 Key supplier defined. A key supplier (including suppliers of Government Furnished Property (GFP) is a supplier at any level whose cost, schedule, or technical performance is essential to the development and production of an effective, affordable system. There are several criteria that can result in a supplier being deemed “key”. A key supplier (including a supplier of GFP) is a supplier at any level whose cost, schedule, or technical performance is essential to the development and production of an effective, affordable system. There are several criteria that can result in a supplier being deemed key:

a. The requirements flow-down process, as shown on FIGURE 8, results in a supplier's "product characteristic" being essential to attaining the "system attribute requirement".

b. A supplier is identified as "sole source" because of unique technologies or unique manufacturing capabilities.

c. A supplier is “single source” due to limited funds or production quantities.

d. Excessive risk, in cost or technical performance, with no low-risk alternative available.

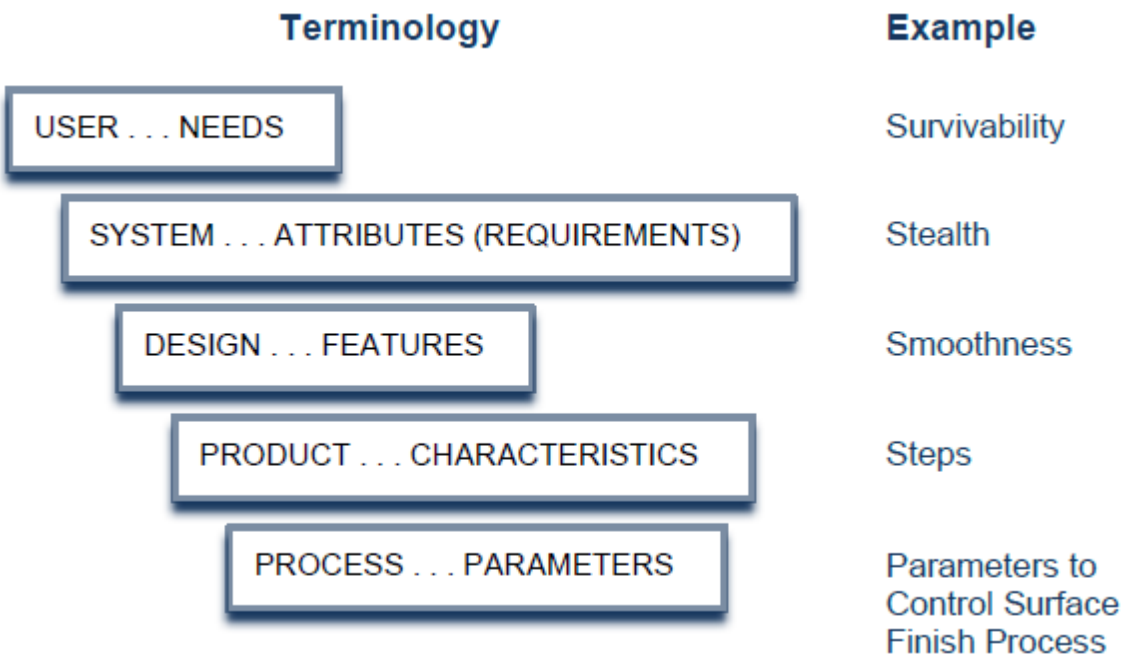

FIGURE 8. Requirements flow-down terminology.

6.5.8.2 Supplier role. Supplier performance becomes increasingly important as the percentage of weapon systems work performed at the supplier level continues to grow. Various studies have shown that, once a program reaches production, supplier activities typically account for more than 70% of the total production cost. Key suppliers are responsible for the full gamut of program activities involved in system acquisition. They perform design tasks, design trade studies, risk management, key product and process identification, and they further flow down authority to ensure that their performance allocations are met. For these reasons it is essential to integrate key suppliers into program planning and development as early as possible so they can participate in the allocation of requirements and design trades as well as resource sharing during the development and detailed design activities.

6.5.8.3 Guidance. Supplier tasks must be fully integrated into the overall program plans and schedules and a plan should be developed which fully describes the supplier management effort. Successful supplier participation in the IPT process requires effective communication of the requirements and goals by the prime contractor. It is intended that requirement flow-down be based on a cooperative agreement. The prime should have an established system for key supplier selection that includes criteria for past performance, proven abilities demonstrated on similar programs, and assessment of supplier capabilities for the technology in question. The system also should address supplier implementation of the practices described in this guide.

6.5.8.4 Incorporating GFP supplier activities and schedules. The supplier management plan prepared by the prime contractor is one way of incorporating key GFP supplier activities and schedules into the overall program plan. If an Associate Contractor

Agreement (ACA) is implemented on a program, the agreement must provide for the participation of key GFP contractors in arrangements and must allow adequate insight into key GFP contractor activities so they can be fully integrated into the Integrated Master Plan (IMP). (ACAs are agreements between contractors working on government contract projects that specify requirements for them to share information, data, technical knowledge, expertise, or resources.) If the contractor identifies a supplier of GFP as key and that supplier's contract with the government does not have adequate ACA requirements, the contractor needs to bring this to the attention of the government program office, who should affect the needed changes to the supplier's contract.

6.5.8.5 Lessons learned. Programs that have not successfully integrated their key suppliers into the overall schedules and plans have commonly had difficulties in meeting their requirements and goals. Sometimes, the supplier base is neglected until the design is formalized, resulting in requirements not being met by suppliers who don’t have the capability to meet design requirements. In addition, the prime contractor may have little insight into supplier schedule slippage and other risk areas. Past performance data on supplier capabilities was often lacking or given less weight than cost in selection activities. Supplier performance lead times factored into overall program schedules have been overly optimistic without margin for delays.

6.5.8.6 Supplier process audits. Weapon Systems have greatly increased in complexity over the last 30 years, and the rate of increase in complexity is accelerating. As system complexity increases, function elements of the system are becoming more complex and a greater number of critical processes are involved in making parts, components, and subsystems. With more components and critical processes come more suppliers. The length, breadth, and volume of the supply chain has also increased significantly. Finally, more DoD suppliers are also involved in commercial fabrication, dividing their attention between commercial customers and military contracts. This leads to a greater quality risk spread over a wider base of suppliers, leaving DoD with a very difficult management challenge.

6.5.8.7 Quality of subcontracted parts. Assuring quality of subcontracted parts used to rely on common specs and standards, and there was less risk a supplier would misunderstand the specification or diverge from contract requirements. Today DoD often buys parts manufactured in the same factory as similar commercial parts. But the military may have tighter quality limits, more stringent processing standards, and longer life requirements given the serious nature of its mission. For example, if a chip on a personal cell phone fails after 100 hours, the phone can be thrown away and easily replaced. If the same chip, or a close cousin, fails on an F-35 avionics suite, the consequences could be catastrophic.

6.5.8.8 Effects of substandard parts. The DoD and aerospace industry needs a way to make sure the critical components precisely follow the specs and process standards necessary to ensure requisite quality. The prime contractor usually has design authority, and it is their job to communicate specification requirements to the suppliers and to make sure the suppliers deliver parts of high quality. But this process sometimes breaks down, leaving the government-contractor team to deal with the significant challenge of what to

do with substandard parts that have already been delivered and installed onto weapon systems. When the supplier process failure doesn't result in a visible, easily found defect, these parts are often spread throughout the system build process. In some particularly painful cases, the quality problems were not identified until discovered by the user during a repair cycle. Back checking through the supply chain uncovered the supplier deviated from the prescribed process months or years earlier, resulting in the great number of parts/systems effected.

6.5.8.9 The need for audits. To prevent this situation, prime contractors, in conjunction with their government customers, should implement audits of critical processes at suppliers. These audits should focus on ensuring that processes are capable and are being followed and that quality escapes are prevented or caught and corrected before they expand to become a major program disaster.

6.5.8.10 Quality audits. There are other quality audits conducted on supplier processes. For example, a Quality System Audit may be done by an outside certification team that is auditing to a standard, like AS9100 or ISO 9001. National Aerospace and Defense Contractors Accreditation Program (NADCAP) is also an example of an organization that certifies manufacturing processes. These audits are general, covering an entire factory or production site, and they do not focus in on special processes for military customers.

6.5.8.11 Additional types of audits. There are also periodic process compliance audits, verifying compliance to quality procedures. These audits focus on how well the facility complies with the procedures they define in their AS9100 compliant quality system. The Supplier Process Audits discussed here are more product focused, with a limited scope. The other two audits described above can be viewed as large nets cast over the entire facility, necessitating a coarser less detailed review. A Supplier Process Audit is a finer detailed review only done on special processes in relation to specific parts critical to a system or product.

6.5.8.12 Guidance. Positive verification of compliance with process specifications is a critical element of supplier quality assurance. This can take the form of a Supplier Process Audit. These audits should be performed periodically on suppliers who perform critical processes, especially processes that cannot easily be visually verified later in the build-up of the system. Heat treatment of a titanium structural part is one example. The proper conversion of the titanium grain structure is the result of time and temperature of the heat treat, and it takes a highly trained metals expert to verify it once the process is completed. However, an auditor watching the process as it is being completed can easily see if the threshold temperatures are reached and held for the minimum length of time.

6.5.8.13 Importance of contract wording. Like other elements of Manufacturing and Quality, getting the right words on contract are critical to getting a program's prime contractor to take action. In source selection, section L and M language should ask for a description of the prime contractor's robust approach to proactively identify quality risks throughout the supply chain. The prime's ability to identify critical parts, processes, and risk suppliers should be clearly expressed on contract, and a plan to audit these parts and processes at these suppliers is an appropriate part of the Quality Plan

and/or Systems Engineering Plan. The aggressiveness of the prime contractor in pursuing audits at critical suppliers, and steps they take to proactively manage quality risk throughout the supply chain, are good items for an Award Fee or Incentive Fee contracting approach.

6.5.8.14 Lessons learned. Two critical elements of successful supplier process audits are team membership and the team's onsite activity. Prime contractors have long had supplier certification audits, but these frequently involved a buyer or contracting officer and a QA specialist, who might not even see the parts involved. They may be simply performing a paper audit verifying requirements are documented in the Purchase Order. A good supplier process audit only starts with this PO flow down check. Supplier process audits will be performed because the process itself is critical, so in order to ensure the process is done properly, the audit team must include experts with process knowledge (for example, a metallurgist for heat treatment processes). Finally, the audit should culminate in the audit team physically watching a part being built by the process in question. Although this is similar to a First Article Inspection (FAI), supplier process audits differ in that they are performed periodically to ensure the process hasn't gone off track.

6.5.8.15 The need to audit suppliers. Many military systems are manufactured on commercial or near-commercial lines. Recent history is littered with programs that took a "hands-off" approach to these acquisitions, assuming that DoD could get good quality without paying for it with money or management attention. Supplier process audits may not be a normal part of contractors' quality management systems, so the government customer should step up and require them contractually. Even without customer attention, prime contractors should ensure their quality systems include this activity and should raise the subject with their customers to ensure proper coordination.

6.5.9 Supplier Quality. A basic quality management system compliant with industry standard ISO 9001 or AS9100 for airborne systems is foundational to producing products that meet contractual requirements. However, it is often necessary to implement tools and techniques that go beyond traditional quality management to ensure the final product meets user needs. Many of these tools and techniques are described within AS6500 and this handbook and focus on the development of stable and capable manufacturing processes. Some companies refer to these techniques as advanced quality systems or as defect prevention practices. For complex weapon systems, the combination of a robust, basic quality management system and the advanced quality/defect prevention practices are critical to successful program execution, and it is mandated under Federal Acquisition Regulation (FAR) Part 46.202-4.

6.5.9.1 The need for a quality management system. An effective quality management system is required for operationally safe, suitable and effective weapon systems. The quality system ensures the as-delivered configuration is the same as the as-designed and as-tested configuration. The quality system serves as the management and control function within the systems engineering process. It requires basic controls over requirements reviews, design inputs, verification and validation of design outputs, and control of design changes. It also requires monitoring and measuring of processes and

products to ensure they conform to requirements. An effective quality system is absolutely critical to ensuring the airworthiness of aircraft. The quality system must have sufficient controls in place to ensure that the delivered aircraft meets all of the requirements of the approved and qualified design. An aircraft that has a qualified design, but is delivered with defects is not a safe, airworthy aircraft.

6.5.9.2 The need for contractual quality specifications. Commercial and commercial derivative aircraft rely upon Federal Aviation Administration (FAA) Production Certification (PC) for this assurance. Prime contractors obtain (and maintain) FAA (PCs) by demonstrating their quality controls are thorough and sufficient. DoD aircraft that are not built under the authority of a PC must rely upon the quality systems that are specified contractually, such as ISO 9001 or AS9100. The government and contractor team must ensure these systems and controls are effective and will always result in compliant products. Federal Aviation Regulations Part 21 (for commercial derivative aircraft) and AS9100 further define effective quality systems.

6.5.9.3 Guidance. The Quality Management System (QMS) and any special tailoring requirements should be specified in the SOW. Program Management (both in the government and at the contractors) should identify the responsibilities and authority for ensuring that all elements of the QMS are documented, deployed, monitored, and measured to ensure they are effective.

6.5.9.4 Cost of Quality (CoQ) defined. Where inspection systems have emphasized the detection of defects after the product has been produced, quality systems are designed to prevent the production of defective products. For this reason, quality managers should strive to understand and systematically reduce the overall Cost of Quality (CoQ) of items produced. CoQ is usually defined as the sum of “failure costs,” “appraisal costs,” and “prevention costs.” There are many different terms in use for this concept (including Total Cost of Quality, Cost of Poor Quality, and Total Quality Cost), with little consensus on the “correct” term. For example, the American Society of Quality often uses the term “Cost of Poor Quality” due to the negative connotation of “Cost of Quality.” However, many aerospace industry primes use “Cost of Poor Quality” to refer to only the “failure costs,” and “Cost of Quality” to capture failure, appraisal and prevention costs.

6.5.9.5 CoQ focus to capture all quality cost. FIGURE 9 provides an overview of CoQ. The quality manager should not get hung up on the differences in terminology. Focus on understanding what term is appropriate to capture *all* the quality costs for a given contractor, and employ that term to drive the right behavior. Regardless of which term is used, Cost of Quality is used in this handbook, it is crucial to understand that CoQ captures many more costs than the traditional Scrap, Rework, and Repair (SRR) metric, also referred to as the Cost of Repair, Rework and Scrap (CoRRS).

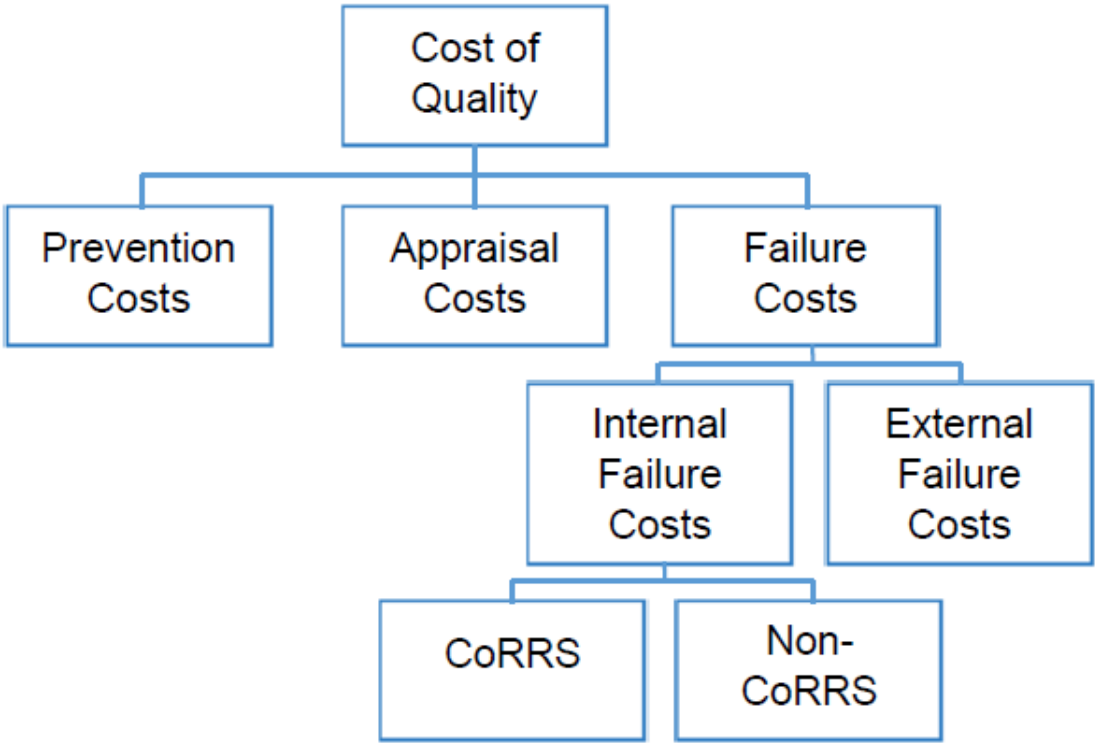

FIGURE 9. Cost of Quality.

6.5.9.6 CoRRS and CoQ compared. CoRRS typically captures only the touch labor associated with repair and rework, and the material replacement cost for scrapped items. CoQ also captures all of the "above the shop floor" and "hidden factory" costs, such as liaison, manufacturing, and design engineering, additional inspections and related quality assurance/metrology activities, Material Review Board (MRB) activities, procurement, among other costs. FIGURE 10 describes costs included in CoQ. CoQ/CoPQ "represents the difference between the actual cost of a product or service and what the reduced cost would be if there were no possibility of substandard service, failure of products, or defects in their manufacture." In other words, any cost that would not have been expended if quality were perfect contributes to the cost of quality. So, even the costs associated with the forklift driver unloading the replacement material are included in CoQ.

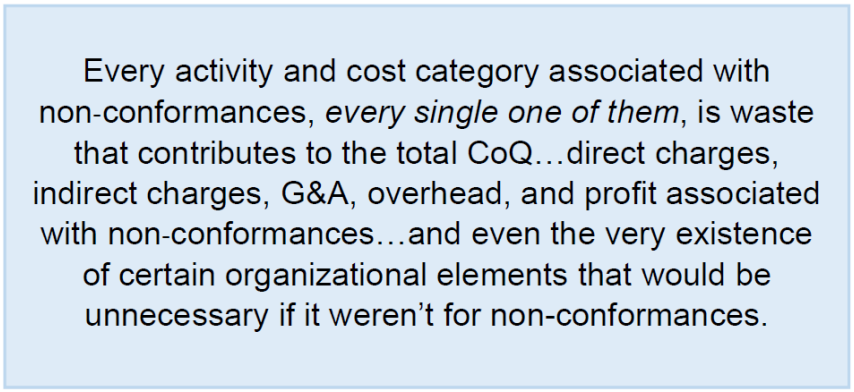

FIGURE 10. CoQ inclusion.

6.5.9.7 Why pursue CoQ. Clearly, CoQ is significantly greater than CoRRS (estimates range from three times to more than six times greater), but the reader may be wondering why it is even important to capture CoQ. Quite simply, the reason for identifying CoQ is to motivate better behavior, and drive a prevention-based quality culture. Many people within industry, including DoD employees, have become "comfortable" with a certain level of quality, believing that non-conformances should be expected based on system complexity and low production rates. As a result, there has been significant emphasis placed on the ability to detect and disposition defects, modest emphasis placed on eliminating defects through thorough root cause analysis and corrective action, and very limited emphasis on preventing defects from occurring in the first place. There is a prevailing view that CoRRS is relatively small and insignificant, especially when fixed price contracts are in place. However, CoQ is much larger than CoRRS with the costs compounded year after year, because inefficiencies associated with poor quality (including direct, indirect, overhead, G&A, and even profits) are recognized as actual and allowable, and thus form the basis (the starting point) for the next year's negotiations. Identifying and segregating the actual CoQ should lead to more informed and rational decisions regarding improvement efforts, and motivate the organization to emphasize prevention over correction. The result of a prevention-based quality culture will be cheaper products, delivered in a timelier manner, with improved inherent quality and reliability. Those who say that the quality of our delivered products is high are right. The reason for pursuing CoQ is because we want to know *how* the high levels of quality were achieved. It is always faster, better and cheaper to build it right the first time. FIGURE 11 shows some examples (not all-inclusive) of prevention, appraisal, and failure costs.

FIGURE 11. Examples of quality costs.

6.5.9.8 CoQ goals. There will always be costs associated with delivering a product. However, the goals are to:

1. shift the focus from detection and correction of failures to prevention of them, and
2. drive systematic process improvements that yield overall CoQ reductions.

FIGURE 12 illustrates CoQ shifts over time when using CPI.

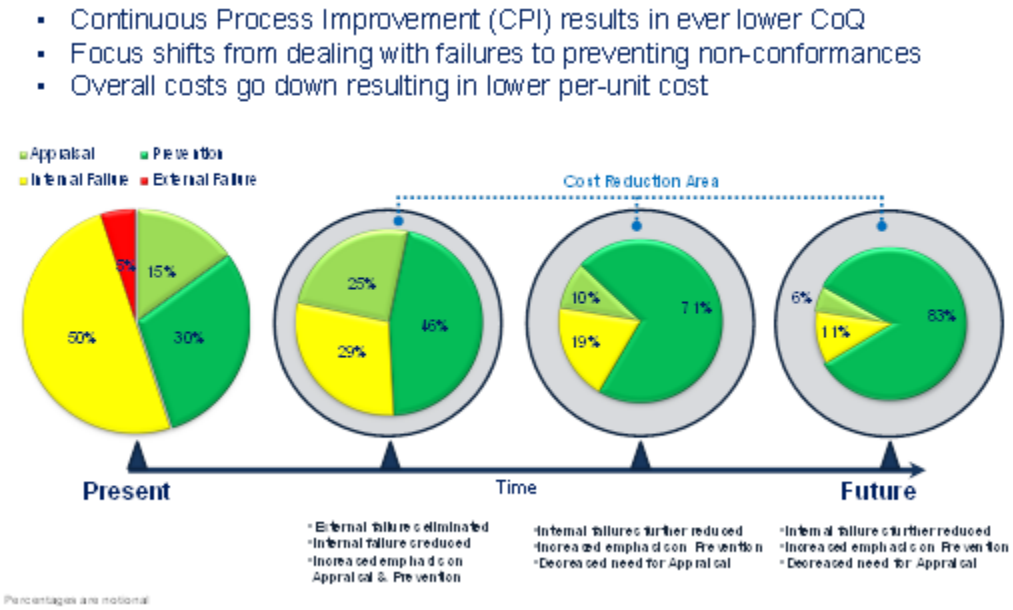

FIGURE 12. Cost of Quality shifts over time.

6.5.9.9 CoQ addressed in contracts. Discovering the true CoQ of our products is not an easy endeavor. The quality manager will encounter significant pushback – certainly from industry, and quite possibly from within the Government. The reason is that costs associated with poor quality are a significant source of revenue, and the prime is not necessarily motivated to reduce such costs. Additionally, the systems and methods for collecting the various elements of CoQ may or may not be sufficiently mature. Although it

would be nice to identify costs at the defect tag level, collecting failure costs at that level and aggregating appraisal and prevention costs at a cumulative level is not a bad place to start. Of course, it all begins with the inclusion (and defense) of contract language requiring the identification and segregation of CoQ. If it's not in the contract, it won't get done!

6.5.9.10 The new role of dedicated quality engineers. The responsibilities under a quality system may be implemented outside the traditional quality assurance organizational structure. Personnel in all functional areas (not just dedicated quality personnel) should be tasked with the responsibility for the quality of their own work and empowered to make key decisions affecting that work. Quality engineers, like manufacturing and producibility engineers, are key members of the IPT. They participate directly in every part of the program, from the early design phase through to production and support. Their role is to ensure an integrated, multi-functional approach to quality throughout the product life cycle.

6.5.9.11 Effective quality management system features. Important features of an effective quality management system, such as AS9100C and ISO9001 include:

a. management commitment to quality and a customer focus.

b. a plan-do-check-act, closed loop, deployment process to ensure deployment/improvement plans are defined, executed, and effective.

c. focus on processes at all levels and functions, within an organization and the interfaces between processes. Processes must be designed to meet customer requirements, to add value to the product, be measured and continually improved.

d. control of design development, purchased products, and production processes and outputs.

e. control of software programs deployed in manufacturing to prevent unauthorized changes. For example, Computer Aided Drafting (CAD) software, Computer Numerically Controlled (CNC) machining programs, measurement and test station programs.

f. continual improvement, control of nonconforming products, root cause analyses, corrective and preventive actions.

g. verification and validation of suppliers, personnel, processes, tests, and products are critical

h. prevention methodologies must be supported throughout the program plan. (KCs, determinate assembly, and others are proven methodologies for accomplishment.)

i. Measurement System Analysis is required for any method used to inspect, validate, or verify product or process.

j. develop surveillance and audit plans that include a physical configuration audit for every aspect of the product build.

6.5.9.12 Industry specific quality requirements. In addition to the foundational ISO 9001, various industries have added unique requirements to this document. For example, the aerospace industry has created AS9100 to include unique requirements for the aerospace industry, such as key characteristics and prevention of Foreign Object Damage. When managing acquisition programs that are considered commercial, the quality manager must be aware of the FAA certification process and the oversight provided by the FAA. The quality manager must determine the extent to which FAA oversight meets the needs of the government, where gaps may exist, and how to cover those gaps.

6.5.9.13 Lessons learned. Quality systems relying solely on inspection have often been proven to be ineffective in assuring the quality of the final product. In fact, the best that inspection based quality systems could hope to do was to identify all defective product that was produced and prevent its delivery to the customer. However, even 100% inspection has been shown to be less than 100% effective in identifying all defects. Prototype and technology demonstration programs often try to take shortcuts in quality management systems. However, attention to details and process and product controls are just as important, if not more so, in dealing with complex, never-before-used technology. Many tests have failed due to improper use or assembly of a $0.99 part.

6.5.9.14 Improving root cause analysis. Root cause analyses are typically the weakest part of a quality management system. Material Review Boards (MRBs), charged with finding the cause of a nonconformance, often jump to the obvious, simple solution. Variability Reduction and Six Sigma tools should be used to conduct a thorough analysis of data to properly determine the true root cause.

6.5.9.15 Analyzing nonconformance. In addition, when the MRB dispositions the hardware, it must analyze the cumulative effects of all nonconformance. Engineers who disposition newly discovered non-conformances must be aware of all the previously identified non-conformances to determine their combined effects on both the part under consideration and the entire system. Numerous minor non-conformances may add up to be a major nonconformance. This is crucial and can be tied to the Unique Identification Data (UID) effort. Critical measurements and a history (like the car history reports from the VIN number) can give a background of the part and some information of surrounding parts. When a problem occurs, we always blame the “straw that broke the camel’s back”, when 99% of the tolerance was already consumed by another piece of the system or multiple pieces that were not at nominal.

6.6 Integrated Master Plan (IMP) Entry Criteria. The following are suggested manufacturing and quality entry criteria that should be accomplished prior to Integrated Master Plan events for major life cycle milestones and design reviews. They are intended as a starting point to identify significant activities and are not intended to be used in their entirety, nor are they intended to be all inclusive. They should be selected and tailored appropriately for the unique circumstances of each program.

6.6.1 Milestone A (Approval to Begin Program):

1. Preliminary production concepts identified. Preliminary cost partitioning of major assemblies accomplished.
2. Preliminary production cost estimate documented, including ground rules, assumptions, and rationale.
3. Materials lacking mature processes identified for manufacturing risk management purposes.
4. IRAD and other programs established to reduce risk.
5. Manufacturing capacity issues identified.
6. Industrial base issues identified.
7. Key technology teams and strategic business alliances initiated.
8. Key supplier risk assessment performed and manufacturing risk mitigation planning initiated.
9. Key supplier performance requirements flow-down and agreement established.

6.6.2 Milestone B (Approval to Enter Development):

1. Areas identified for producibility studies
2. Initial cost estimates support program goals and cost risks and drivers are identified
3. Preliminary production cost model (PCM) developed
4. Plan developed for assessing manufacturing capabilities
5. All risk reduction activities factored into program schedule and IMP.
6. Industrial facilities and manpower requirements identified.
7. Risk assessment and events/activities for key suppliers included in Integrated Master Plan.
8. Simulations demonstrate ability to meet producibility and affordability goals.

6.6.3 Interim Event (corresponding to Preliminary Design Review):

1. Preliminary Manufacturing and Quality Plans developed
2. Initial Contractor Production Cost Model developed and under formal configuration control.
3. Manufacturing Readiness Level Assessments conducted
4. Risk abatement milestones included in IMP.
5. Process capability database includes all key processes.
6. Supplier capacity risks identified and included in risk management planning.
7. Key suppliers identified and selected and subcontracts negotiated.
8. Key supplier concurrence with requirements allocation and flow-down accomplished.
9. Key supplier identification of preliminary key product characteristics.
10. Identification of preliminary key product characteristics complete.
11. Identification of preliminary key processes complete.
12. Plan developed to verify and validate new processes.

6.6.4 Interim Event (corresponding to Critical Design Review):

1. Manufacturing and Quality Plans updated
2. Process capabilities are adequate for product requirements for prime and subcontractors.
3. Production cost estimates demonstrate cost objective is achievable
4. Cost mitigation actions are being completed
5. Producibility studies have been completed and recommendations are incorporated in the product design
6. Simulations have been conducted to verify production plans, taking into account facility manpower, and process limitations
7. Selection of production processes complete, including comparison of required process capabilities to documented capabilities.
8. Manufacturing Readiness Level Assessments updated.
9. Test article build plan complete.
10. Key supplier detailed designs complete.
11. Key supplier identification of key process parameters complete.
12. Final key product characteristics determined.
13. Final key production process parameters determined.
14. VR Program plan is in place

15. Initial process control plans have been developed
16. Process capability studies are being conducted with results fed back to product design.
17. VR metric developed.
18. All ST/STE scheduled for verification and validation before LRIP.
19. Plan in place for conducting First Article Inspections and process proofing.

6.6.5 Milestone C (Approval to Enter Production):

1. Production cost estimates demonstrate production cost requirements are achievable with acceptable risk.
2. Manufacturing Readiness Level Assessments conducted.
3. Simulations verify and validate assembly processes prior to LRIP.
4. All process control plans for critical processes have been developed and are in place.
5. Final Build-to documentation complete, including identification of key characteristics and control plans for key characteristics.
6. Process capability data is being collected on processes affecting KCs and is available to the IPTs
7. Process stability and capability have been determined for key processes. For those with insufficient data, estimates of stability and capability have been made.
8. Process improvements have been initiated for processes with unacceptable variation
9. Metrics are used to measure the progress of the VR program
10. All First Article Inspections and Process Proofing activities have been completed. Plans are in place to correct findings.
11. Continuous collection and periodic review of production and quality data occurs to identify areas for improvement.
12. Key supplier risk assessment and abatement planning complete and being implemented
13. Verification/validation of key supplier process control and VR processes evaluated routinely
14. Implementation initiatives focused on elimination of non-value-added activity and/or optimization of production cycle time (such as Lean Aerospace Initiative).

7. NOTES

7.1 Intended use.

This handbook provides guidance in the application of SAE AS6500 to DoD programs.

7.2 Subject term (key word) listing.

Critical Manufacturing Processes

Factory Efficiency

Key Characteristics

Key Suppliers

Manufacturing Readiness Levels

Process Control

Process Failure Modes Effects Analysis

Process Validation

Producibility

Production Readiness Reviews

Quality

Quality Management System

Statistical Process Control

Supplier Management

Supplier Process Audits

Variability Reduction

Virtual Manufacturing

7.3 Changes from previous issue.

Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes.

CONCLUDING MATERIAL

Custodians:
Army – AV
Navy – AS
Air Force – 11

Preparing activity:
Air Force – 11
(Project SESS-2016-009)

Review activities:
Army – CR
Navy – SA

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.dla.mil.