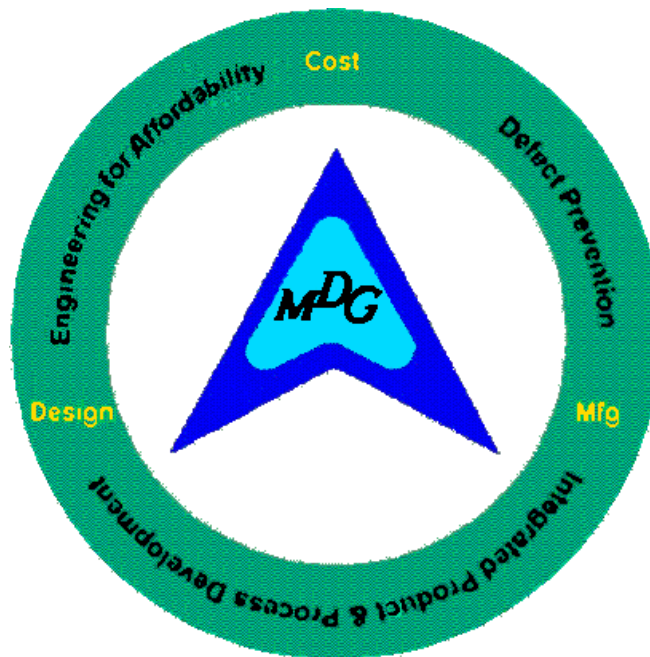




*Manufacturing
Development Guide
August 2008*



DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited. Request shall be referred to ASC/ENSM, 2530 Loop Road West, Wright-Patterson Air Force Base, OH 45433-7101, Phone: (937) 255-9581, Reference 88th ABW Public Affairs Document # WPAFB 08-5065, disposition date 8/14/2008.

Table of Contents

<i>Executive Summary.....</i>	<i>4</i>
<i>Chapter 1: INTRODUCTION</i>	<i>8</i>
1.1 The Purpose of the Manufacturing Development Guide	8
1.2 A Statement of the Problem.....	8
1.3 Root Cause	10
1.4 MDG Success Criteria	11
1.5 Manufacturing Development Guide Technical Content	12
1.6 The Relationships among Practices	13
1.7 Benefits	13
1.8 Relationship to Operational Safety, Suitability & Effectiveness (OSS&E)	14
1.9 Relationship to Airworthiness Certification.....	14
1.10 Relationship to Manufacturing Readiness Levels	14
<i>Chapter 2: ACQUISITION STRATEGY</i>	<i>16</i>
2.1 Financial Considerations	16
2.2 Contracting Considerations	18
<i>Chapter 3: MANUFACTURING / PRODUCIBILITY ENGINEERING'S ROLE IN IPPD.....</i>	<i>20</i>
<i>Chapter 4: ENGINEERING FOR AFFORDABILITY AND PRODUCIBILITY</i>	<i>24</i>
<i>Chapter 5: QUALITY SYSTEMS</i>	<i>30</i>
<i>Chapter 6: BEST PRACTICES GUIDELINES</i>	<i>34</i>
6.1 Introduction	34
6.2 Manufacturing Capability Assessment and Risk Management.....	35
6.3 Production Cost Modeling	38
6.4 Key Suppliers	41
6.5 Key Characteristics and Processes	43
6.6 Variability Reduction.....	47
6.7 Virtual Manufacturing	53
6.8 Design Trade Studies	57
6.9 Process Failure Modes Effects and Criticality Analysis	60

6.10 Product and Process Validation	65
6.11 Manufacturing Process Control and Continuous Improvement	67
6.12 Factory Efficiency (Lean Factory).....	69
6.13 Technology Obsolescence & Diminishing Manufacturing Sources (DMS)	72
<i>Appendix I: MDG Acronyms.....</i>	<i>i</i>
<i>Appendix II: Statement of Work Inputs</i>	<i>iii</i>
<i>Appendix III: Other RFP Inputs</i>	<i>iv</i>
<i>Appendix IV: Integrated Master Plan (IMP) Exit Criteria.....</i>	<i>vi</i>
<i>Appendix V: Suggested Inputs for Instructions to Offerors and Evaluation Criteria (Sections L and M)</i>	<i>x</i>
Instructions to Offerors Guidance (Section L)	x
Evaluation Criteria Guidance (Section M)	xi
<i>Appendix VI: Reference Material.....</i>	<i>xiv</i>

Executive Summary

This document is about improvement in business systems and processes. It was initially developed by a joint government/industry team to provide guidance for the improvement of weapon system acquisition. It presents information for implementing systems and practices in defense acquisition programs that will help ensure effective and efficient contract performance. Intended primarily for Air Force acquisition personnel and their contractor counterparts, any organization interested in improving their operations will find help in the topics and guidance presented.

The Manufacturing Development Guide (MDG) is fully compatible with the Air Force and DoD's Manufacturing Readiness Level and Manufacturing Readiness Assessment (MRL/MRA) initiative. MRAs will be conducted on weapon systems to determine their manufacturing maturity and readiness to proceed to the next level of acquisition. MRAs will use specific criteria to evaluate the current level of manufacturing readiness and many of these criteria cover practices that are described in the MDG. If programs and contractors implement the MDG practices, they will be in an excellent position to progress successfully through the Manufacturing Readiness Levels.

MIL-HDBK-896, dated 8 August 2008 and titled "Manufacturing and Quality Program," contains the MDG practices in a succinct format and serves as an excellent tool to contractually implement these practices. Further guidance on use of this MIL-HDBK is in Appendix II.

The Manufacturing Development Guide consists of: (1) an introduction; (2) discussion of acquisition strategy elements which are affected by an MDG implementation; (3) Manufacturing Engineering's Role in Integrated Product and Process Development (IPPD); (4) Engineering for Affordability & Producibility considerations; (5) Quality systems concepts with an emphasis on defect prevention; and (6) a set of 12 best practices and their application throughout the acquisition life cycle. Appendices contain suggested wording for Statements of Work, Integrated Master Plan criteria, and Sections L & M wording.

Affordability has become a primary metric for the weapons acquisition community, and the failure to develop and procure affordable weapon systems now ranks as the number one challenge for major weapon system programs. The objective of the MDG is to make the tools and techniques that drove the quality revolution in the commercial sector available to defense program customers, contractors, and suppliers.

One of the most important objectives of the MDG is to integrate manufacturing engineering considerations early in the development phases of weapons system acquisitions. The goal is to make significant design and manufacturing decisions early in the development process, thereby realizing substantial cost avoidance and risk mitigation associated with these decisions. When we drive manufacturing development earlier in the development cycle, issues critical to affordability, schedule, and product performance

can be balanced. It is in the development stage that manufacturing guidance will have the most impact on the life cycle of the program.

A problem confronting government program managers today is how best to convey in Requests for Proposals (RFP) the need for contractors to utilize the concepts that are now being successfully applied in today's competitive global economy. It is important to identify proven best practices and concepts and structure programs to implement these concepts. The MDG was created specifically to address these issues. It enables management to identify practices that a program should employ to maximize affordability and performance payoffs while achieving quality. The MDG, along with MIL-HDBK-896, offers flexible, specific language for tailoring and insertion into the government's solicitation package and for incorporation into the contract. The guide's applicability may vary, depending on the program and acquisition process being utilized.

The MDG Best Practices in Chapter 6 are briefly summarized below:

1. Manufacturing Capability Assessment and Risk Management

The manufacturing capability assessment and risk management effort is a structured, disciplined approach to evaluating manufacturing capabilities, identifying and assessing risk, and developing risk mitigation plans to maintain an acceptable level of risk. The principle objective is to identify appropriate actions to assure that manufacturing processes mature along with product design so that they will be available to support the production and support acquisition phases.

2. Production Cost Modeling

The intent of this practice is to provide a Production Cost Model (PCM), which can be used to estimate the projected production cost of the proposed design and compare against a threshold value for affordability. It will be used in the trade studies practice to assess and accumulate design-related costs (associated with the factory).

3. Key Suppliers

Key suppliers should be integrated into the Integrated Product Teams (IPTs) as early as possible to take full advantage of their product and process knowledge, foster innovation, knowledge-sharing and continuous improvement throughout the supplier network. The supplier network ought to be structured such that it is linked to enterprise vision and strategy. They should be selected based on their proven record to perform and on their ability to satisfy program needs.

4. Key Characteristics and Processes

Key Characteristics are design features whose variation significantly impacts product performance, quality, cost, or safety. Key production processes determine a product's conformance to design, and they are the major drivers to achieve cost and performance goals. The identification of key product characteristics and their design limits, along with the identification of key production processes and their capabilities, are basic engineering

tasks, which should be performed in the development phase. These tasks are intended to support variability reduction and continuous improvement in the Development and Production phases, and to facilitate cost-effective product improvement activities. Key Characteristics provide a unique thread linking requirements, design, manufacturing, and support.

5. Variability Reduction

Variability reduction is a systematic approach to reducing product and process variability in order to improve cost, schedule and performance. It is based on the concept that just meeting specification limits is not the best measure of quality. Rather, the degree of variability of a key process and its relationship to design limits (process capability) becomes the measure of merit. During development, data collection and process control procedures are established, process capabilities are calculated based upon available data, and feedback is provided to the designers on the ability to meet proposed tolerances. These efforts are essential to assess process capability and stability in preparation for the production decision. Variability reduction efforts during production are primarily concerned with continuous improvement in product quality and manufacturing process efficiency.

6. Virtual Manufacturing & Virtual Prototyping

Virtual Manufacturing is an integrated manufacturing approach which effectively addresses materials, processes, tooling, facilities, and personnel issues involved in a product's design and manufacture before the product and process designs are released while changes can be implemented with less cost. A combination of virtual manufacturing and virtual prototyping capabilities enables the IPT to accomplish three important objectives. They are: (1) validate product designs and production processes in a virtual environment; (2) evaluate the performance characteristics of a variety of product configurations; and (3) make effective cost and performance trades during early development activities.

7. Design Trade Studies

A design trade study is the analysis of program design characteristics to support a development trade-off of system cost, schedule, and performance in order to achieve the best possible balance of capabilities. The design trade-off considerations should include production processes, tooling, test equipment, and support equipment issues. Desired and threshold values are defined for each system performance parameter, and trade studies provide the ability to optimize system design within these values.

8. Process Failure Modes Effects and Criticality Analysis

The purpose of a Process Failure Modes Effects and Criticality Analysis (PFMECA) is to identify potential failures in a manufacturing process, rank the criticality of the failure types and to identify actions to mitigate the failures. The primary use for PFMECA is the early identification of potential failure modes so they can be eliminated or minimized quickly. The PFMECA is most effective when initiated during the design stage, before

failure modes have been incorporated into a process. It should be performed iteratively during the design phase, and the PFMECA results should be inputs to the process design and redesign.

9. Product and Process Validation

The focus of Product and Process Validation is on methods of verifying the capabilities of production equipment and processes. The rapid development of effective virtual manufacturing and virtual assembly tools has provided additional methodologies by which many of the objectives of conventional line proofing can be met. The decision to use line proofing, virtual tools or some combination of the two to support a particular program will require an analysis of the comparative cost, schedule, and quality impacts.

10. Manufacturing Process Control and Continuous Improvement

During production, the responsibility of the manufacturing engineering function is to focus on the effective control of the manufacturing processes and on the orderly incorporation of improvements in both product and process. Contracts should be structured to provide incentives for continuous production phase improvements, schedule gains, enhanced affordability, reduced acquisition cost, and enhanced supportability.

11. Factory Efficiency

Factory efficiency is achieved by the continuous application of all appropriate lean manufacturing practices, high performance manufacturing systems, and continuous improvement practices and principals during production. It extends far beyond the confines of the factory floor to include such issues as risk management and the long-term impact of make-buy decisions on the industrial base.

12. Obsolescence and Diminishing Manufacturing Sources

Technology Obsolescence is a reality in today's rapid race to the next best technological solution. Where there once were product cycles that lasted years, some product life cycles are now measured in months if not weeks. The need to ensure weapon systems are sustainable years into the future is a major challenge, and it requires a unique set of tools to deal with obsolete parts when they arise. In order to prevent obsolescence, and to minimize the impact where it is not preventable, the use of an evolutionary approach to system development and sustainment is a wise precaution.

Chapter 1: INTRODUCTION

1.1 The Purpose of the Manufacturing Development Guide

The purpose of the Manufacturing Development Guide (MDG) is to promote the timely development, production, and fielding of affordable and capable weapon systems by addressing manufacturing and quality issues throughout the program acquisition cycle. Its primary focus is to identify and encourage the use of proven manufacturing and quality related technical and business practices to achieve this purpose. Primary customers of the guide are engineering and program management personnel at the Air Force Materiel Command's (AFMC) Acquisition Centers and their defense contractors.

1.2 A 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: (1) Difficulty in developing, producing, and fielding supportable new weapon systems, modifications, and upgrades in a timely and affordable manner; and (2) Difficulty in smoothly transitioning an acquisition program from development to production.

The Timely Fielding of Affordable Systems

Our difficulty in fielding mature systems in a timely and cost effective manner has been a persistent problem experienced to some degree on nearly every program. The symptoms and impacts of these problems vary according to the observer's perspective, but many of the main issues are summarized below:

Acquisition Community

Symptoms: Frequent modifications to design specifications and performance measures.

Impacts: This results in high initial acquisition costs, and the need for excessive engineering support to stabilize the design and manufacturing processes. It also creates production schedule slips and early and frequent engineering changes.

User Community

Symptoms: Late deliveries and the inability of the system to meet all requirements, especially in the areas of reliability and supportability.

Impacts: Delay in Required Assets Availability (RAA) and reduced operational capability (particularly in sortie generation).

Support Community

Symptoms: High initial repair rates, unexpected failure modes, and excessive configuration changes.

Impacts: Increased spares requirements, excessive failure analyses and corrective actions, more complex configuration tracking systems, and numerous technical order changes, resulting in increased costs and the potential inability to maintain adequate operational capabilities.

Transition to Production

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 (1) the lack of an effective plan for the development and maturity of production processes during the pre-production acquisition phases concurrent with product development; (2) not understanding the linkage between key design requirements, the processes needed to support them, and the impact on product performance, supportability, and cost; (3) ineffective risk assessment, mitigation, and monitoring activities supporting critical process development; and (4) lack of clear and concise vertical and horizontal communication links throughout the supply chain.

Acquisition Community

Symptoms: Late deliveries of early production units, high initial acquisition costs, recalls, and retrofits.

Impacts: Increased costs, production schedule slips, and early and frequent engineering changes.

User Community

Symptoms: Late deliveries and the inability of the system to meet all requirements, especially in the areas of reliability and supportability, increased costs to operate.

Impacts: Unreliable performance and operational readiness.

Support Community

Symptoms: High repair rates, unexpected failure modes, and maintain larger number of spares.

Impacts: Support lifecycle costs exceed initial plan for supportability

1.3 Root Cause

A root cause analysis indicates that a major source of these problems is the lack of thorough consideration of the capability and stability of production processes to support production and operation of the weapon system products. This problem can be characterized with the following statements:

Inadequate response to high production risk at the start of the program:

- Lack of understanding of existing process capabilities (process characterization).
- Limited source selection criteria related to process capability.
- No long-range production investment strategy as part of the overall acquisition strategy.
- Unstable requirements and no reasonable match between requirements and existing process capabilities.
- Lack of programmatic focus on the need for balanced simultaneous product and process development.

Lack of attention to process capability during development:

- Insufficient or untimely consideration of producibility analyses.
- Product design instability resulting from an emphasis on meeting performance requirements without consideration of producibility.
- Insufficient identification of key product characteristics and key process parameters (product characterization).
- Late initiation of production planning and risk mitigation efforts.
- Lack of exit criteria for key processes and a lack of process related milestones.

No consideration of process control in production:

- Lack of process control requirements.
- Lack of identified key product characteristics and/or key process parameters for monitoring and controlling.
- Deficiency in process improvement efforts.
- Lack of hard cost control requirements or incentives to control / reduce life cycle cost.

Little to no emphasis on process capability for field support/sustainment:

- Failure to address supportability issues and field environment during design.
- Lack of attention to the maturity and future availability of spare parts.
- Lack of attention to required repair procedures.

1.4 MDG Success Criteria

To achieve the MDG's purpose as stated earlier, the following success criteria and supporting practices are stressed.

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

- Balanced investments in both product and process during the pre-Production program phases.
- Consideration of process capability in the technology development and technology insertion efforts.
- Incorporation of 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.
- A well-defined production investment strategy as part of the overall acquisition strategy.
- Establishment of capabilities for realistically evaluating the balance of the technical, cost, and schedule aspects of the total system through such techniques as linked cost and performance models and electronic simulation of the manufacturing and support environments.

Achieve a balance of product/process development during each phase of acquisition by:

- Identification of exit criteria for all key events and milestones appropriate to developing, establishing, and validating required process capabilities.
- A dedicated effort to stabilize the product design early in the development program through balanced trades between performance, cost, and schedule, with attention to producibility and supportability.
- Earlier accommodation of 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.
- Modeling and simulation of the design, production, and support environments.

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

- Requirement flow down practices which identify key product characteristics, key production processes, and key process parameters throughout the supply chain.
- Well-defined process control practices identified in the build-to data package.
- Implementation of 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.

Consider field support/sustainment process capability and environment during product development by:

- Development of maintenance and repair processes during the product development phase.
- Determining product and process capabilities for spares through identification of key product features and process requirements in the build-to package.
- Adequate planning for support of the product starting with initial deployment.

1.5 Manufacturing Development Guide Technical Content

The objective of this document is to provide a technical understanding of the practices presented, along with guidance on including, where appropriate, these concepts in the RFP and contract, and assessing their implementation success throughout the acquisition process. The MDG includes 12 distinct practices to address the success criteria described above. Each chapter is summarized below:

Chapter 2, Acquisition Strategy, addresses contractual and financial strategy issues impacting the implementation of MDG practices.

Chapter 3, Manufacturing Engineering's Role in Integrated Product and Process Development (IPPD), describes the heightened importance of the manufacturing engineer's mission in the integrated product team environment. The involvement of manufacturing engineering in the product definition process provides for early identification and mitigation of producibility issues, cost issues, and potential transition-to-production risks.

Chapter 4, Engineering for Affordability & Producibility, addresses how weapon system costs, both flyaway and life cycle, must be treated as system requirements equal in importance to quality, reliability, and technical performance. This section describes dedicated producibility, affordability, and value engineering programs.

Chapter 5, Quality Systems, addresses the correlation between the tools and techniques contained in this guide and concepts that many companies have implemented as part of their modern Quality Systems. Both emphasize the importance of quality in the development process to achieve producible designs; quality in the design of capable, controlled manufacturing processes; and quality through the prevention of defects rather than after-the-fact detection of defects.

Chapter 6, Best Practices Guidelines, addresses the 12 MDG practices that should be implemented to help assure producible and affordable weapon systems that meet the user requirements.

Appendix I contains acronyms used throughout the guide.

Appendices II-V contain recommended RFP and contract language, including sample language for Statements of Work (SOWs), Integrated Master Plan (IMP) exit criteria,

Proposal Instructions to Offerors (Section L), and Evaluation Criteria Guidance (Section M). In addition, sample Statement of Objective (SOO) language is provided to convey the government's expectations for manufacturing and quality during the acquisition process.

Appendix VI, Reference Material, provides a reading list to help amplify and explain many of the concepts in the MDG.

1.6 The Relationships among Practices

Many of these MDG best practices rely on receiving input from other MDG best practices to achieve the largest return on investment. Inputs from disciplines outside of manufacturing are also required for the best solutions. For example, the Production Cost Modeling practice benefits from well-executed practices covered in the MDG sections on Manufacturing Engineering's Role in IPPD, Engineering for Affordability, and Virtual Manufacturing. These practices are usually less effective when implemented singly or in a discrete sequential fashion.

1.7 Benefits

MDG practices represent a significant change in the way the defense industry operates. Achieving the full range of benefits available from the MDG 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 MDG practice activities throughout the life of the program is essential. The benefits resulting from implementation of MDG practices include:

- Shorter development schedules and reduced cycle times.
- Better first article quality.
- Development of robust product designs.
- Easier transition of designs to production.
- Better supplier product integration.
- Quicker resolution of problems.
- More effective risk management.

These benefits have been shown to be achievable by a number of studies and through actual experience on a variety of programs. It is also imperative that the tools, techniques, and systems the MDG promotes be tailored to the individual program.

1.8 Relationship to Operational Safety, Suitability & Effectiveness (OSS&E)

Air Force Policy Directive 63-12 assigns Single Managers the responsibility to ensure and preserve the operational safety, suitability, and effectiveness (OSS&E) of their weapon systems. Air Force Instruction (AFI) 63-1201 describes mandatory acquisition process elements required to assure OSS&E. MDG principles and practices impact the following elements within AFI 63-1201:

- Use of a disciplined engineering process
- Evaluation of Total Ownership Costs (TOC)
- Ability of maintenance and repair sources to deliver quality products
- Capability of supply sources to produce parts and supplies that preserve OSS&E

Many of the MDG practices support the achievement of these process elements:

- Identification of Key Characteristics -- plays a critical role in maintaining a disciplined engineering process by guiding design engineers through an analysis of the most critical product characteristics.
- Production Cost Modeling -- should be used to develop, understand, and evaluate Total Ownership Costs and the impacts of design and management decisions on TOC
- Manufacturing Process Capability Assessment -- facilitates the matching of key characteristics with process capabilities to ensure the production and delivery of quality products that preserve OSS&E.
- Quality Management Systems -- must be implemented to assure the as-delivered products meet the as-designed configuration.
- Key suppliers -- suppliers must have sufficient capability to meet design requirements and be evaluated to assure they have effective quality programs in place.

1.9 Relationship to Airworthiness Certification

Airworthiness Certification, as governed by MIL-HDBK-516, contains specific Manufacturing and Quality criteria that must be met for 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 assure design tolerances are met. When the MDG is fully implemented, it is intended to satisfy those criteria. However, it is the responsibility of the Chief Engineer to verify the criteria have been met.

1.10 Relationship to Manufacturing Readiness Levels

Manufacturing Readiness Level (MRL) definitions were developed by a joint DoD/industry working group under the sponsorship of the Joint Defense Manufacturing Technology Panel (JDMTP). 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.

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.

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 MDG practices. For example, MRL criteria address producibility studies, key characteristics, production cost models, and quality systems. Therefore, implementing the practices described in the Manufacturing Development Guide will enable successful achievement of target MRLs.

Chapter 2: ACQUISITION STRATEGY

2.1 Financial Considerations

Two financial issues are associated with implementation of the approaches recommended in this guide. The first is a change in development funding profiles to support doing the right tasks at the right times. 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 in the following subsections.

Funding Requirements for Development and Production

Perhaps the most important business issue related to implementation of the MDG is how to properly fund programs with these new requirements. In practice, implementation of the MDG will produce significantly different funding profiles than those experienced on past programs, as Figure 2-1 illustrates.

In comparison to historical programs, those programs that incorporate MDG principles may require earlier funding, but the benefits of this earlier investment will greatly reduce life cycle costs, including non-recurring production costs, through the substantial elimination of errors and change orders later in the program.

The MDG 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 should be improved over that of historical programs. These improvements will more than offset any additional early development costs.

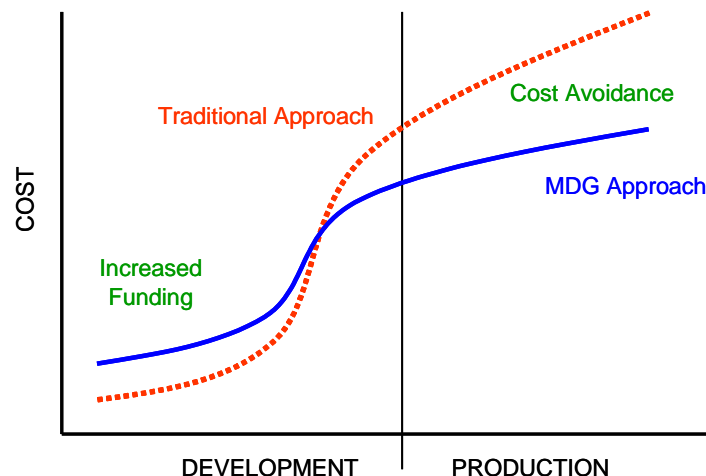


Figure 2-1. A Comparison of MDG and Traditional Program Funding Profiles

MDG Cost Estimating Considerations

Development Phase - Cost estimating considerations for the development phase must now consider the effects of the additional MDG activity. The MDG promotes a number of acquisition approaches that require greater effort up front. Engineering and tooling hours will shift to an earlier point in the program as we integrate the design and manufacturing efforts sooner. The benefit, however, is that leading defense contractors have reported that design changes can often be reduced by 50% or more. On the F-15 program it's been estimated MDG-related practices would have reduced tooling costs by 40%.

The MDG also recommends the involvement of suppliers early in the design process. It is probable that this requirement will necessitate additional costs in the Material/Subcontract area during development. While the total number of suppliers will not increase, the amount of their non-recurring cost will, since they will be brought into the program team to assist in the design phase. The amount of this increase would depend on the number of suppliers involved and how early in the process their involvement begins. We should also expect supplier related design changes to decrease (with a corresponding decrease in costs) because of earlier supplier involvement in the design process.

Production Phase - Production phase costs and cost estimating will also be affected by the MDG initiatives. The MDG-influenced up-front investment in development should continue to produce significant cost payoff in production. Initial cost projections on the JSF Technology Demonstration Program showed unit production cost avoidance due to MDG implementation to be 20% to 30% of the affected hardware budget.

Specific areas of increased production efficiency that can be expected from the use of MDG practices include:

1. Redesign of the system should be significantly reduced. Traditionally, systems and processes have been designed in the development phase with changes being made from late in development through early production. This design and tooling rework should be significantly reduced.
2. With design and manufacturing processes better integrated with manufacturing and the use of defect prevention techniques, the amount of scrap, rework, and repair traditionally associated with manufacturing will be reduced.
3. Since major subcontractors have been involved in the design process, integration of their components into the system should be more efficient. This should be reflected in labor hour savings for all major functional disciplines and more beneficial cost improvement curves. It should also be reflected in fewer engineering changes related to supplier activity.
4. Manufacturing labor should start at a lower first unit or T1 cost and proceed down a cost improvement curve that parallels and is below the historical non-MDG curve, as depicted in Figure 2-2. Better integration of the design and manufacturing process should

bring about a less costly first unit. Traditionally, first unit costs have been high because of the significant amount of manufacturing and re-manufacturing needed to incorporate producibility design changes. This, coupled with the inefficiency of incorporating these changes late in the process, caused high T1 costs and steep cost improvement curves. MDG practices should create lower first unit production costs and improve efficiency by moving both prime contractor and subcontractor labor to a later portion of the cost curve.

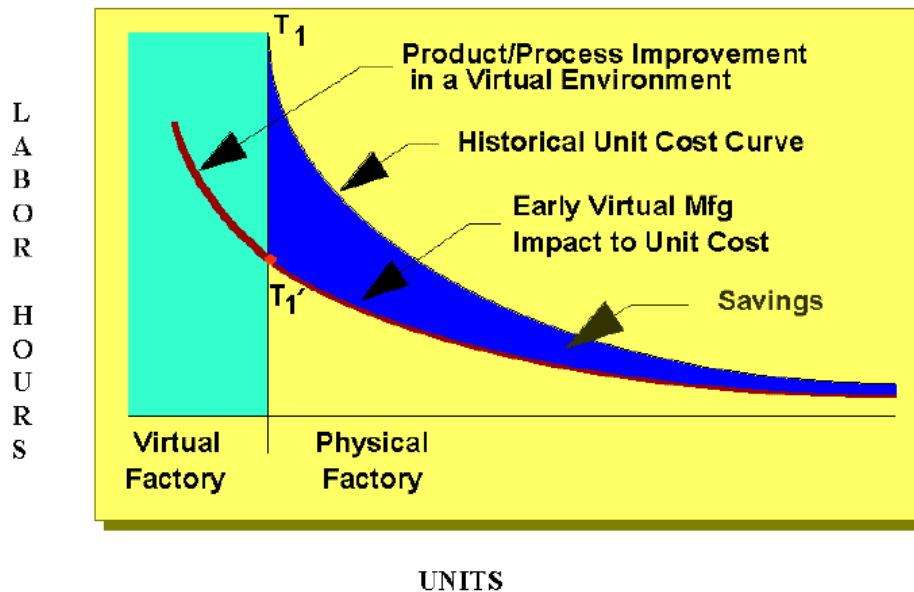


Figure 2-2. Product/Process Improvement in a Virtual Factory Environment

2.2 Contracting Considerations

MDG implementation may be a disincentive for some contractors because its effect is to reduce overall acquisition cost and thereby reduce contractor profit. Some contractors may desire a contractual incentive or contractual funding to perform certain MDG practices (such as variability reduction activities). Others will perform these MDG recommended initiatives as a natural part of their systems engineering process. Contractors should be encouraged to view MDG practices as a critical tool in the execution of their general business. To ensure these practices become a natural part of contractor cultures, carefully worded contractual incentives may be appropriate.

A recent Independent Review Team discovered that contracts often lack contractual Manufacturing and Quality requirements, resulting in a lack of emphasis on producibility and significant difficulties in transitioning to production. The team also found that the appropriate focus was only applied in response to problems. As a result, the team recommended that robust Manufacturing and Quality requirements be included in Statements of Objectives and Statements of Work. Examples of contractual requirements are contained in Appendices II and III. These requirements should be carefully incentivized to ensure sufficient attention is provided to producibility, quality, and supplier management and that best practices are truly implemented.

Incentives may include:

- Negotiation of target price curves (price targets for multiple lots that assume the use of some MDG concepts, but allow the contractor a share in the savings if the costs are below the curve)
- Award fees (to motivate improvements and best practices on existing contracts). Examples are included in Appendix III.
- A Value Engineering Program (allows sharing of savings)
- Multi-year contracts (a longer-term commitment on the part of the government to encourage long-term contractor investment.)

Chapter 3: MANUFACTURING / PRODUCIBILITY ENGINEERING'S ROLE IN IPPD

3.1 Introduction

In the collaborative design process which characterizes Integrated Product and Process Development (IPPD), the prime contractor, the major subcontractors/suppliers, and the government customer work together in an Integrated Product Team (or IPT) environment. The objectives of the IPT are: 1) refine user requirements and transform them into a performance-based system or component specification, 2) provide a plan for effectively validating, verifying, and executing a design that fulfills these performance requirements, and 3) develop production and support tools and processes to support production of the system as designed. It is an essential condition of the IPPD environment that the contractor's manufacturing/producibility engineering function is directly involved early in the product definition process. It is also essential that the government Manufacturing Systems Engineer (MSE) actively participates in, and where appropriate leads the government's participation on IPTs throughout all phases of a program. This chapter describes the IPPD process and the roles of the contractor's manufacturing/producibility engineering (ME or CME) function as well as the government's MSE.

Pre-system design efforts and exchanges serve to inform the prime contractors of the customer needs. These include a continuing dialogue with industry, study contracts, advanced technology demonstrations, reviews of draft documents, and technology maturation contracts for risk mitigation. Contractor feedback to the government during this period assists in identifying the cost and risk drivers in the proposed acquisition.

Early on, the IPT must assure their inputs into design trade studies to balance the product design with the manufacturing processes. This requires accurate information about the capabilities of all related processes, not just the factory floor. This includes the entire value chain of all partners and suppliers. The MSE must identify the data and analytical tools used to define the necessary process capabilities, and assure that all IPT members have access to it. As the design evolves, the fabrication and assembly options become constrained by the details of the design, materials selection, imposed tolerances as well as the other physical aspects of the proposed part. The MSE must be able to use producibility and affordability metrics to monitor the translation of the design decisions into system specifications in order to identify unforeseen consequences affecting system performance, cost or schedule. These values will help the IPT make informed and balanced trades among design options, and accurately assess and manage program production risk.

There will be two distinct types of MSE responsibility during the production and operation phases. The first will focus on improving the efficiency of the existing or derivative manufacturing processes. Using factory data (and any field or test data

available), the MSE examines manufacturing processes to see if they can be made more robust or their variation reduced. Processes, like products, are susceptible to variation in inputs, environments, etc. Reducing this susceptibility improves process robustness. IPT participation in the integration of major systems improvements, modifications or other system design changes constitutes the second major MSE responsibility. And the MSE should proceed with these design changes by implementing the appropriate MDG practice as if they were new starts.

3.2 Rationale

The objective of the development phase is engineering and manufacturing development, not engineering then manufacturing development. The IPT must be as concerned with the ability to manufacture the proposed design as with its functionality. Just as component testing confirms the proposed part's functionality, the MSE must have the same quality of data about the manufacturing process to fairly represent the ability to manufacture the parts. Process capabilities from the existing factory floor or data collected from benchmark industries can be used by the MSE to help establish the basis for affordability analysis. Unique materials or tolerances for which manufacturing data does not exist may require process testing, demonstration, or simulation by the MSE. These efforts would be functionally equivalent to the testing that is currently done by the design engineer to reduce risks on new component designs.

To assure the proper matching of production processes with product characteristics and their effect on system performance, process capability data must be analyzed during product and process development. Contractors and suppliers throughout the value stream should be encouraged to establish and populate a Manufacturing Capabilities database identifying present capability and any areas where risk exists requiring further process development or changes to the product design or design requirements.

The transition to production has traditionally brought with it many unpleasant surprises in the form of cost and schedule slippage due to low process yields, poor quality, or failures in assembly and final check out. Low Rate Initial Production (LRIP) was introduced as one mechanism to mitigate the transition to production risks. LRIP gives the IPT an opportunity to identify and resolve some of these problems, however, LRIP itself does not address the root cause of the transition to production problems. The MSE must encourage the IPT to an earlier focus on the root causes of affordability and producibility problems. Focusing on preventing these problems during development helps prevent detrimental program impacts during the transition to production. If problems do arise the emphasis must be on identifying and correcting the root cause of the deficiency, either in the design of the system or production processes.

Variability reduction in the production phase requires the MSE to use selection and prioritization tools, such as the Pareto analysis and Quality Function Deployment (QFD), to find and focus on the processes most critical to the program success or to provide the best return on investment. Simulation of the factory, and many related processes, also proves useful in prioritizing improvement efforts. Regardless of how candidate processes are selected, the objective for the MSE is continuous improvement of the efficiency and

effectiveness of factory operations. Candidate processes should also include the support operations or "above the factory floor" activities. Analysis and use of data, management by fact, should be the basis of all decisions.

As the program moves into Production, the MSE becomes a leader in the continuous improvement of the product and processes. In this phase, the IPT has two areas of focus. First, using field and factory data, the manufacturing processes are examined to see if they can be made more robust or their variation reduced. Second, if new performance requirements are identified or obsolete parts arise (parts no longer available from suppliers), the resulting design improvements are planned and introduced in a disciplined manner, such as block release of design changes.

3.3 Guidance

The government Manufacturing Systems Engineer's responsibilities include insight to these tasks:

- Participate in design trade studies
- Develop and refine Production Cost Model (PCM)
- Initiate mapping of the Key Characteristics Process for requirements
- Establish data collection for process capability requirements
- Initiate process development as required (when data reveals process capability is less than desired to ensure a match between product requirements and process capability)
- Participate in Integrated Risk Assessments
- Implement manufacturing capability assessments
- Integrate key supplier activities into manufacturing activity
- Develop production plan
- Validate production plan through simulation
- Implement variability reduction
- Implement defect prevention activities
- Participate in Integrated Risk Assessments and implement appropriate risk mitigation initiatives

Production phase tasks for the Manufacturing Engineer (with participation of the MSE) include the following:

- Monitor process variation and initiate improvements.
- Plan for cost-effective implementation of changes.
- Implement Lean initiatives for cost management.
- Maintain the PCM.

- Continue defect prevention program.
- Identify and React to Indicators

3.4 Lessons Learned

Customer participation creates an atmosphere which supports cost-effective performance-based resolutions to design trades. Supplier participation provides a vehicle for a “best value” approach to the performance trades and cost objectives at the lower levels of the design effort.

Misuse of variability reduction tools can create misinformation and could adversely impact the processes, so the MSE must have a good working knowledge of statistics and experience with the full tool set of variability reduction techniques. The maintenance of a Manufacturing Capability database derived from statistical process control and other factory data collection systems provides a source for identifying continuous process improvements.

Product changes must be introduced into the existing factory in the least disruptive and most cost-effective manner. Changes to tooling and test equipment, processes, and the product flow require coordination and planning. Successful companies have authorized the ME to model before and after processes, employing simulation techniques to reduce errors which would impact cost and schedule.

Chapter 4: ENGINEERING FOR AFFORDABILITY AND PRODUCIBILITY

4.1 Introduction

One of the primary purposes of the MDG is to improve product affordability. Designing a producible system is the key to affordability. This chapter provides a general discussion of several approaches. Today's acquisition environment is highlighted by a competition among weapon systems for limited procurement dollars making affordability as critical as performance. Engineering for affordability and producibility must be performed during all phases of a program for both new developments and modifications.

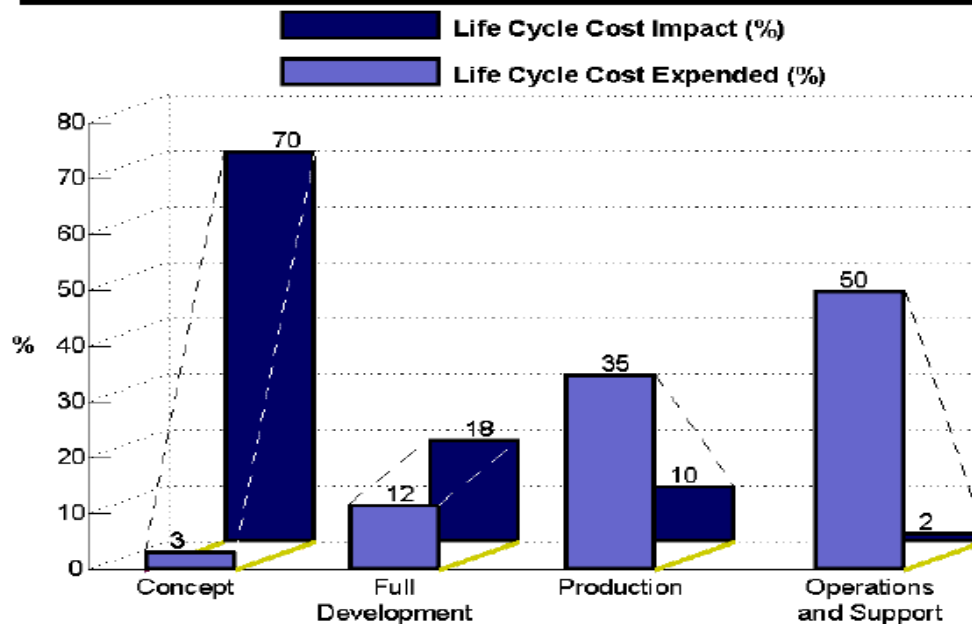
In general, there are four approaches to engineering for affordability which can be combined as necessary to create the best tool for the circumstance: (1) affordability as a foundational responsibility for all engineers; (2) a dedicated producibility program; (3) a distinct affordability program; and (4) a value engineering program.

4.2 Rationale

Limited defense budgets mandate affordable programs. This environment has led to major changes in the way development programs are managed and executed. Total Ownership Costs (also known as Life Cycle Costs) are now a crucial factor in determining weapon system feasibility. All new programs must emphasize cost as a primary contract requirement and must analyze the total ownership cost impact of all systems requirements.

Studies have repeatedly shown that the best opportunity for reducing system cost occurs during the early phases of program development (Figure 4-1). As the chart depicts, a small percentage of the life cycle cost is actually expended in the early phases but the decisions made in the concept development phase drive the majority of the life cycle costs. Therefore, it is critical that IPTs use affordability-enhancing practices as soon as possible.

Concept Development Disproportionately Impacts Life Cycle costs



Source: **Producibility Measurements Guidelines**, NAVSO P-3679, Dept. of the Navy, August, 1993

Figure 4-1. Impact of Early Activities on Life Cycle Cost

Several factors drive increased weapon system's cost and many are rooted in increasingly rapid technological advancements. Design complexities and integration difficulties often result in extended development times and increased costs. Long development cycles also increase the risk of diminishing manufacturing sources and part obsolescence. This drives the costs for redesign, production, and maintenance and forces the AF to develop or pay a premium to maintain sources for old parts in a market where they have only a limited military application.

4.3 Guidance

Affordability as a Foundational Responsibility: First, government and contractor senior leadership must explicitly direct that affordability is the responsibility of every member of the program, not an element applied solely by manufacturing engineers. This is analogous to the concept that quality ("Big Q") is everyone's responsibility, not just the Quality Assurance organization. As an example, design trade studies within every IPT and engineering discipline must address cost.

Second, management must continually place an emphasis on Total Ownership / Life Cycle Costs. Design-To-Cost (DTC) and Reduction of Total Ownership Cost (RTOC) programs provide a management framework to help assure affordability requirements are met. DTC and RTOC programs both allocate (or partition) the overall cost requirement down to lower level IPTs where each is given its own cost targets, goals, or requirements. The overall program cost requirements may be defined in different ways (as shown in

Figure 4-2), depending upon how much of the cost is to be included. Traditionally, DTC goals usually focus only on flyaway costs and RTOC initiatives focus on total Life Cycle Costs.

A common approach for characterizing the overall program cost requirement is to use the Average Unit Production Price (AUPP). AUPP may be defined as the flyaway cost divided by the production quantity.

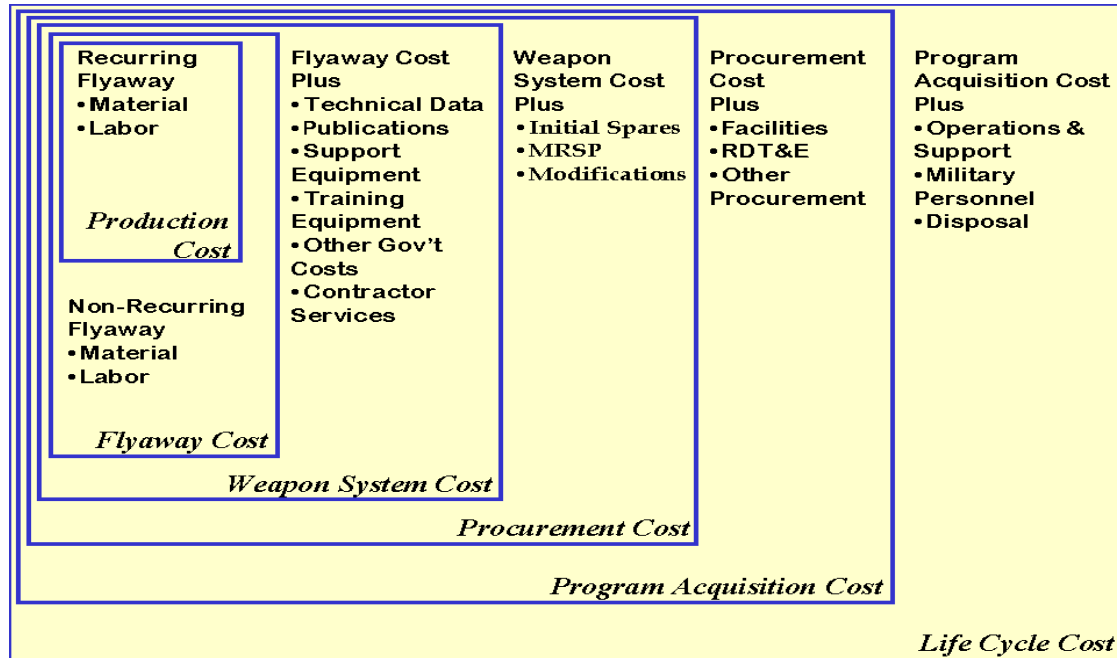


Figure 4-2. Life Cycle Costs - Total Ownership Costs

Third, management must also provide tools to all engineering disciplines to analyze and optimize cost in their areas. The tools must have the flexibility to trade product performance against projected production costs. Production Cost Models, discussed further in Chapter 6: Best Practices Guidelines, should be used to estimate the impacts of design decisions on manufacturing costs and evaluate design alternatives within the context of affordability. IPTs should also develop and maintain affordability metrics and analyze them as part of their continuous improvement activities.

A Dedicated producibility/affordability effort contributes significantly to improving life-cycle cost when integrated into the overall Systems Engineering process. A good source of information for producibility for DoD contracts is “Producibility Measurement For DoD Contracts” published in November of 1992. Some of the other key elements of an effective producibility program include Manufacturing Capability Assessments and Determinant Assembly.

Producibility Measurement For DoD Contracts is divided in two parts – ‘A’ and ‘B’.

Part ‘A’ addresses questions regarding: ‘What do we need to do to ensure we address producibility correctly. Part ‘B’ provides guidelines on ‘How to measure producibility?’

Additionally, this book provides useful producibility measurement checklists for both the contractor and the DoD program offices. 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 measurement of the producibility initiatives.

A dedicated producibility effort contributes significantly to improving producibility and affordability when integrated into the Systems Engineering process. Manufacturing Capability Assessments, Determinant Assembly, and use of Monolithic parts are among a few tools and techniques for manufacturing cost reduction.

Manufacturing Capability Assessments, further discussed in Chapter 6: Best Practices Guidelines, relate to engineering for affordability by providing the design engineers an understanding of manufacturing capabilities. These capabilities should be fed back into the design to result in a more producible product, consistent with the inherent capabilities of the existing processes.

Determinant Assembly is an 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 aircraft program was able to reduce aircraft assembly time by 1200 hours per shipset in just one area (Bilge Longerons).

A Distinct Affordability Program: To increase the focus on affordability, some programs have implemented a separate affordability program. An Affordability Program Plan should be developed to describe the program, processes, and roles and responsibilities of the contractor and government. The primary processes within an affordability program include: identifying cost drivers; developing potential initiatives for reducing these costs; evaluating the cost/benefits of each potential initiative; reviewing, prioritizing, and approving each initiative for implementation; and monitoring their implementation. To fund these projects in a fixed-price environment, the government typically must have a separate funding for the investments, or the program team must develop a unique contractual arrangement to provide financial incentive to the contractor. This incentive often simply shares a small portion of the long-term reward that is anticipated as a result from these projects, to cover the short-term cost of their implementation.

A Value Engineering Program: Value Engineering (VE) is an organized effort to analyze the functions of a system for the purpose of achieving the essential functions at the lowest life cycle cost, while still meeting all performance requirements. VE programs can either be ongoing, level of effort tasks to continually look for design improvements, or case-by-case submissions of ideas. Under either approach, the contractor will submit Value Engineering Change Proposals to the government and may share in the projected savings if they are approved. The Federal Acquisition Regulations (Part 48) provide more

detailed guidance on cost and savings sharing arrangements and contractual requirements.

4.4 Lessons Learned

Effective use of producibility/affordability application can have dramatic program impacts in terms of program cost, cycle time reduction, quality improvement and overall parts count. Besides lowering the cost of the product, producibility tools and techniques also may include intangible benefits such as simplifying engineering, planning and tooling and ultimately providing the customer with a better product.

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

1. Assemblies with high Realization Factor (RF)
2. Assemblies that are time-consuming or difficult to assemble
3. Assemblies consisting of many parts
4. Assemblies consisting of expensive or difficult to manufacture parts
5. Assemblies or parts which have experienced excessive failures in the field which could possibly be improved by a more robust design
6. Finally, areas having a high cost of quality
7. Assemblies with a large number of shims

Successful implementation of producibility initiatives for the cargo floor of a recent Air Force aircraft program replaced 22 extrusions with 8 machined parts, resulting in installation of 4000 fewer fasteners and a net program savings of \$8.7 million in material, detail parts and assembly cost over the life of the program.

The use of affordability engineering practices is most effective when they are flowed 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 affordability tools and techniques.

Affordability Programs: Cost Reduction Initiatives (CRIs) should be formally documented and the documentation must include the baseline (“before” implementation) costs and “after” costs, as well as the nonrecurring costs to implement the initiative.

It is often difficult to distinguish initiatives that are “over & 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 CRIs 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 ones that improve the *efficiency* of the work must be more carefully evaluated.

Keep cost reduction ideas flowing. The F-22 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 will decrease primarily due to the reduced number of units that will experience the benefits. The F-22 Program also 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. The implications are, start early in implementing CRIs and, second, don’t give up when the initial round of ideas have been exhausted.

Chapter 5: QUALITY SYSTEMS

5.1 Introduction

A basic quality management system, such as ISO 9001-2000, 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 the MDG 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 defect prevention practices are critical to successful program execution.

5.2 Rationale

An effective quality management system is required for Operationally Safe, Suitable and Effective weapon systems. The quality system assures 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. Commercial and commercial derivative aircraft rely upon FAA Production Certification for this assurance. Prime contractors obtain (and maintain) FAA Production Certificates (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 9000 or AS9100. The government and contractor team must ensure these systems and controls are effective and will always result in compliant products.

5.3 Guidance

Program Management in the early phases of the life cycle should define the Quality System, special tailoring requirements, and responsibilities and authority for ensuring that all elements of the Quality System are documented, deployed, monitored, and ensured effective.

Where conventional quality systems have emphasized the detection of defects after the product has been produced, state-of-the-art quality systems are designed to prevent the production of defective products. Advanced quality systems may be implemented

outside the traditional quality assurance organizational structure. Personnel in all functional areas (rather than dedicated quality personnel) should be tasked with responsibility for the quality of their own work and empowered to make key decisions affecting that work.

In response to these developments, some companies have begun questioning whether there is still a need for an independent, dedicated quality functional organization. However, far from eliminating the need for quality professionals, the acceptance of responsibility for their own work by other members of an organization frees up the modern quality organization to perform work consistent with the long-term focus of state-of-the-art quality systems.

Quality engineers, like manufacturing and producibility engineers, are key members of the program IPT. They participate directly in every part of the program, from the early design phases all the way through to production and support. Their role is to ensure an integrated, multi-functional approach to quality throughout the product life cycle.

Important features of an effective quality management system, such as ISO 9001-2000, include:

- Management commitment to quality and a customer focus.
- A Plan-Do-Check-Act “Closed Loop” Deployment Process to assure Deployment/Improvement Plans are defined, executed, and effective.
- A 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, and be measured and continually improved.
- Control of design development, purchased products, and production processes and outputs.
- Continual improvement, control of nonconforming products, root cause analyses, corrective and preventive actions.
- Verification and Validation of Suppliers, Personnel, Processes, Tests, and Products are critical
- Prevention Methodologies must be supported throughout the program plan. (KCs, Determinate Assembly, etc. are proven methodologies for accomplishing this.)
- Measurement System Analysis are required for any method used to inspect, validate, or verify product or process
- Develop Surveillance and Audit plans that include a Physical Configuration Audit for every aspect of the product build.

Depending on the circumstances, the traditional role of independent inspector/tester quality personnel may still be necessary (such as for flight safety items or other mandated inspections), but the main focus should be proactive support rather than reactive policing. Quality personnel should provide the quality tools and quality perspectives needed to support the personnel who are directly adding value to the product, rather than

distributing notifications when they discover non-conformances. The contractor should coordinate and collaborate with the customer on requirements and expectations, thus determining the appropriate method to evaluate products and processes.

In addition to the foundational ISO 9001-2000, various industries have added unique requirements to this document. For example, the aerospace industry has created AS9100 to include, in addition to the basic ISO 9000 system requirements, unique requirements for the industry. These requirements address areas such as control of key characteristics and prevention of Foreign Object Damage. Air Force quality managers should examine AS9100 for applicability to their respective programs and consider it for implementation.

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 to what extent the FAA oversight meets the needs of the government, where gaps may exist, and how to cover those gaps.

Many of the specific practices addressed elsewhere in this guide are grounded in modern quality system tools and concepts, including key characteristics, variability reduction, supplier management, virtual manufacturing, and product and process validation. The tools and techniques that make up state-of-the-art quality systems are referred to as defect prevention techniques. This is consistent with the Joint Aeronautical Commanders Group (JACG) document titled *Engineering and Manufacturing Practices for Defect Prevention: A Guide for Aerospace Acquisition Management Teams*. The JACG guideline discusses attributes, tools, and business practices associated with successful modern Quality Management Systems. Further information on defect prevention tools and processes not discussed in the MDG itself can be found there. These principles are applicable to all phases of an acquisition program.

5.4 Lessons Learned

Traditional quality systems have often been proven to be ineffective in assuring the quality of the final product. In fact, the best that traditional, inspection based, quality systems could hope to do was to identify all defective product that was produced and prevent its delivery to the customer. Even 100% inspection, however, has been shown to be less than 100% effective in identifying all defects. In addition, the role of the quality professional as policeman, looking for infractions, writing citations when they find one, and walking away to let the violator deal with their problem, has led to mistrust and adversarial relationships. The prevalent culture also led many to believe it was the inspectors, not the people producing the product, who were responsible for quality of the product.

To deal with this negative environment, some companies eliminated inspectors and told manufacturing personnel they were now responsible for their own work. What they often found, however, is that as long as independent inspectors are finding defects they still have an important role to fill. It is only after they stop finding defects, assuming defects are no longer being produced, that inspectors are no longer needed. Even then, it is often wise to continue some level of objective, statistical-based inspections as a verification of

the continued stability and capability of the manufacturing processes. Inspection, however, should not be the primary role of quality organizations. Much more is to be gained from the work of quality professionals by having them work with processes, personnel, and other resources to create and sustain a culture of continuous improvement.

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.

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 (see Appendix VII reference material) should be used to conduct a thorough analysis of data to properly determine the true root cause.

In addition, when the MRB disposes the hardware, it must analyze the cumulative effects of all nonconformance. Engineers who disposition newly discovered nonconformances must be aware of all the previously identified nonconformances to determine their combined effects on both the part under consideration and the entire system. Numerous minor nonconformances 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 Carfax report from the VIN number) can give you a background of the part and some information of surrounding parts. When a problem happens, 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.

Chapter 6: BEST PRACTICES GUIDELINES

6.1 Introduction

The program office and contractor must implement MDG practices early in the program life if they are to realize the long-term benefits. A prerequisite for effective implementation of the MDG practices is the participation of the manufacturing engineering, producibility engineering, and quality engineering functions in the early development of the IPPD process. The large number of MDG practices that fall under the manufacturing umbrella functionally should emphasize the necessity of manufacturing/producibility/quality engineering participation.

Some of these best practices may be more applicable in certain phases than in others. The matrix below indicates which practice applies in each phase.

MDG Practice	Concept & Tech Dev	Sys Dev & Demonstration	Production & Deployment
Mfg Capability Assessment & Risk Mgt	X	X	X
Production Cost Modeling	X	X	X
Key Suppliers	X	X	X
Key Characteristics	X	X	X
Process Variability Reduction		X	X
Virtual Mfg	X	X	X
Design Trade Studies	X	X	
Process FMECAs		X	X
Product & Process Validation		X	X
Mfg Process Control & Continuous Improvement		X	X
Factory Efficiency		X	X
Technology Obsolescence & DMSMS	X	X	X

During the Development phases, the MDG objectives are met by involvement of the manufacturing/producibility/quality engineers and by stressing the importance of production cost as a high priority product design requirement. Emphasis is placed on evaluating the producibility of design options so that production risk and cost can be appropriately traded off with system performance. In addition, the foundation of defect prevention techniques is laid in preparation for further implementation in the Production phase.

During Production, positive outcomes are achieved by enabling an environment of continuous improvement in product quality and production efficiency through the application of defect prevention techniques, continued supplier involvement in Integrated Product Teams (IPTs), and an effective variability reduction effort.

6.2 Manufacturing Capability Assessment and Risk Management

6.2.1 Introduction

The manufacturing capability assessment and risk management effort is a structured, disciplined approach to evaluating manufacturing capabilities in order to identify and assess risk early in the design process. Risk is defined as any factor that could cause a program to miss a goal, objective or performance requirement or to exceed cost or schedule constraints. Once risks are identified, the IPT can develop and execute risk mitigation plans in order to maintain an acceptable level of risk throughout the acquisition program and the product life cycle. The active participation of manufacturing engineering early in the IPPD process is intended to reduce the risk of transition to production and to reduce total program cost through the avoidance of engineering changes and rework later in the program. Because weapon system acquisitions often include multi-company teams and multiple subcontractors, the capabilities of teammates and preferred suppliers -- and the integration of GFP contractors -- must be considered in the risk management effort.

While risk is called out separately here in order to emphasize specific concerns related to manufacturing, manufacturing risk should always be fully integrated into the program-wide risk management effort. In fact, this is one of the key responsibilities of the manufacturing engineering representative on the IPT in the development phase. The principles set forth in this section should therefore be considered as continuous with the Program Management, Systems Engineering and other relevant sections of the RFP. Design trade studies and requirements verification efforts will be the source of much of the risk identification and assessment.

New approaches such as virtual manufacturing, virtual prototyping, and virtual assembly minimize transition difficulties by simulating factors that will contribute to risk before production actually begins. Rate build-up capability can be assessed using these same approaches. While factory simulation and virtual prototyping can provide the government clearer insight into manufacturing risks, the contractor remains responsible for the maturity of his production capabilities.

If additional development of production capabilities is required as the design evolves, the contractor should rely on incremental verification steps to validate that the required maturity has been achieved. In the production phases of today's acquisition programs, the role of the government Program Office's manufacturing engineer may include identifying the best value source and providing manufacturing risk assessment to the program manager. Concern with manufacturing capability risk often leads to a formal evaluation at the contractor's facility prior to negotiation of a contract. This is traditionally called a Manufacturing Management/Production Capability Review (MM/PCR). After the source is selected the manufacturing component of program risks must be understood and properly communicated to the government program manager on a regular basis. The contractor's manufacturing manager and government's manufacturing engineer must work together to help propose and evaluate best value solutions to the identified risks.

6.2.2 Manufacturing Capability Assessment and Risk Management Rationale

A manufacturing capability assessment and risk management effort that starts early and is maintained throughout the development process is a key part of the IPPD approach to weapon system acquisition. Applying the same disciplined systems engineering approach used for product development to the development and qualification of the production processes lowers both transition risk and overall program risk.

The reduction of risk associated with manufacturing, as well as assessing its potential effect on the transition to production and final product cost, must start with active manufacturing engineering participation on the integrated product team. A high percentage of program cost is "locked in" by decisions made during the earliest phases of an acquisition program. Recognizing this fact leads to an appreciation of the importance of a balanced, integrated product team, including key suppliers, in the earliest program phases.

From an affordability perspective, the design features should reflect current rather than future process capabilities. The advantages of new materials and processes that offer weight, performance and cost benefits must certainly be considered, but the management of the cost, schedule and quality risks associated with new materials and processes must be included in the consideration. These elements must also be balanced with the issues of sustaining industrial base readiness and key capabilities within an austere acquisition environment.

In addition to the careful identification and management of the risks associated with product and process development, it is essential that thorough planning for production occur early in development. Virtual manufacturing tools, maximum use of production processes during the build of test articles, and line proofing are techniques that provide for enhanced producibility.

6.2.3 Manufacturing Capability Assessment and Risk Management Guidance

The contractor should demonstrate a formal process for identifying and managing risks associated with the manufacturing capabilities of the team and the key suppliers who will participate in the program. One example of a structured methodology is the Integrated Risk Management (IRM) process developed jointly by the Air Force and industry.

An excellent approach to determining manufacturing capability is the Manufacturing Readiness Assessments (MRA). MRAs were developed by OSD's Joint Defense Manufacturing Technology Panel and described on the Defense Acquisition University's Production, Quality and Manufacturing (PQM) webpage. Production Readiness Reviews should also be used to evaluate progress in implementing MDG practices.

The fundamental responsibility for recognizing key component capacity constraints and providing adequate risk mitigation rests with the contractor. Contractors should be encouraged to identify the Internal Research and Development (IRAD) efforts and internal investments in materials and processes that are part of the risk mitigation effort for new acquisition programs.

Typical (not inclusive) Manufacturing Capability considerations are:

- Industrial Base (including increasingly important parts obsolescence and DMSMS)
- Design Stability/Robustness/Producibility
- Quality Management Systems
- Software capabilities
- Material
- Material and subsystem supplier Lead-times
- Technical Data Package
- Surge/Mobilization Capacity
- Manufacturing Technologies
- Work Instructions
- Labor and Facility Resources
- Tooling (capability to design and produce)
- Process/Tooling Proofing
- Measurement (Statistical Management or Variance Analysis)
- Special Tooling or Test Equipment
- Overall Capacity for total production quantities
- Out-sourcing and sub-tier supplier management

6.2.4 Manufacturing Capability Assessment and Risk Management: Lessons Learned

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.

A close air support aircraft program from the mid-1970s in which the adverse consequences of not identifying and managing manufacturing capability risk had serious consequences provides a classic lesson learned example. It was discovered subsequent to source selection that the prime contractor was lacking both manufacturing capability and the capacity required to satisfy production aircraft delivery schedules. The Air Force ultimately had to furnish a significant quantity of machine tools and related production equipment to help resolve the shortfall.

Experience in the 70's and early 80's with late identification of contractor production capability problems led to the establishment and institutionalization of Manufacturing Management/Production Capability Reviews (MM/PCRs). MM/PCRs are often conducted as an integral part of the source selection process. The first major MM/PCR was performed in concert with the Air Combat Fighter (later designated F-16) source selection in 1976. Positive MM/PCR results included not only the generation of critically needed inputs to Source Selection Evaluation Boards (SSEBs) and Advisory Councils (SSACs), but also led to greatly increased defense industry attention to production planning.

The T-38 Propulsion Modernization Program, even though a build-to-print effort, still had numerous manufacturing capability risks identified by the competing small businesses. The Program Manager, in consultation with the Director of Manufacturing, assigned high priority to manufacturing capability and included a substantial manufacturing evaluation in the source selection.

6.3 Production Cost Modeling

6.3.1 Introduction

Cost realism and credibility are primary concerns in our budget-constrained environment. Early, frequent, and increasingly accurate Production Cost Modeling becomes extremely important. The PCM should 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 must address all design driven cost elements and be updated to stay current with the evolving product design and production plans. This model will have three major attributes:

- (1) the ability to be used in design trades to assess the cost impacts of specific design changes, alternative production processes or process improvements
- (2) the ability to incorporate the most recent actual manufacturing costs into the production cost estimate
- (3) the ability to support Finance and Contracting processes (such as independent program estimates, proposal preparation, fact-finding & negotiations, budgeting, and what-ifs.)

6.3.2 Production Cost Modeling Rationale

The PCM will play 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, will help determine whether to proceed to the next phase.

The need for a PCM is also driven by the need to improve Department of Defense and defense industry performance in accurately predicting cost requirements. The Nunn-

McCurdy law regulates acquisition programs. DoD must notify congress when major defense acquisition programs experience an increase of at least 15% in the average procurement unit cost. Breaching this threshold obviously brings a great deal of pressure and oversight to bear on the program and program survivability is in question.

6.3.3 Production Cost Modeling Guidance

The intent of Production Cost Modeling 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.

Accurately modeling production costs with high fidelity during early development is extremely difficult. 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.

For the contractor to develop a valid cost model, the government must define specific parameters to be used as assumptions in the model. 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.

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.

Total Ownership Costs define true system affordability, but they are difficult to predict with confidence during early development. Therefore, a Production Cost Requirement (PCR) within the System Specification is recommended as a more verifiable cost element. When combined with development cost, the PCR provides the baseline cost against which design trades can be evaluated. To balance cost, a cost requirement must be defined and must play an equal role in the systems engineering trade process. The establishment of a Production Cost Requirement in the System Specification facilitates

this effort. Production Cost Modeling enables evaluation of the product design cost estimates against the PCR in the System Specification and permits realistic and timely cost/performance trade studies.

Recognizing the intent is to define most probable cost and the ability to model production cost accurately at the start of development is virtually impossible, there will always be an uncertainty interval associated with the resultant estimate. This uncertainty interval will be relatively large early in the development phase, but should continuously shrink as the design and process capabilities solidify.

PCM focuses on production phase costs, support costs are no less important. However, there are a number of other product performance requirements (such as reliability, maintainability, and availability) that can be used as metrics for assessing progress in controlling support costs. On some programs, a Total Ownership Cost model may be required for projecting support, maintenance, spares inventory, storage, and disposal costs.

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.

6.3.4 Production Cost Modeling 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 production cost modeling 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.

To be effective and credible, the Production Cost Model 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 Key Suppliers

6.4.1 Introduction

Key supplier partnerships and strategic business alliances have become critical factors in today's defense system acquisitions. Partnerships foster joint commitments between companies and promote shared investments in product design and development. Resource sharing and mutually focused internal research and development activities result in aggressive, efficient problem solving and product development. It is not the intent of these guidelines to promote a business strategy of either exclusive partnerships or sustained competition. Rather it is to promote supplier participation in the program teaming structure and in proposal, development, and design activities as soon as the business strategy decision is made. This early supplier participation will allow the team to exploit complementary strengths, address weaknesses, and take mutual ownership of problems and solutions.

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:

- The requirements flow-down process, as shown in Figure 6-1, results in a supplier's "product characteristic" being essential to attaining the "system attribute requirement".
- A supplier is identified as "sole source" because of unique technologies or unique manufacturing capabilities.
- A supplier is "single source" due to limited funds or production quantities.
- Excessive risk, in cost or technical performance, with no low-risk alternative available.

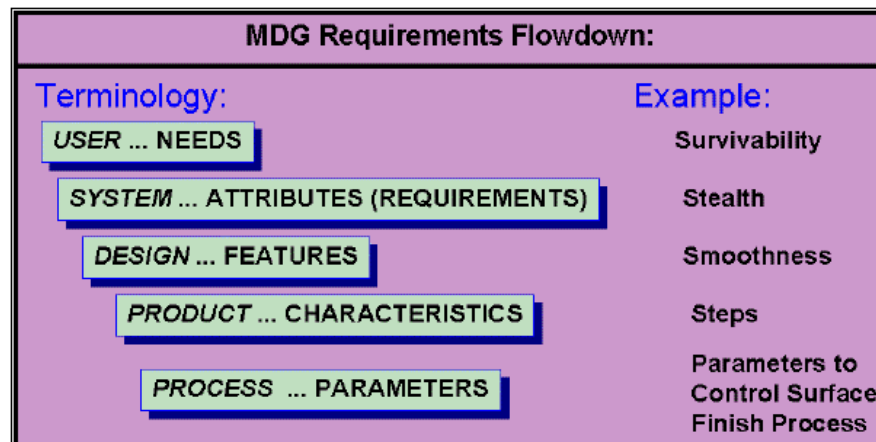


Figure 6-1. Requirements Flow-down Terminology

6.4.2 Key Suppliers Rationale

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 60% of the total production cost. Key suppliers are responsible for the full gamut of program activities involved in system acquisition. They perform design tasks, trade studies, risk management, key product and process identification, and they further flow down authority to assure 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.

6.4.3 Key Suppliers 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 IPPD 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.

The use of Government Furnished Property, Equipment, Services, and Facilities (GFP) represents a special area of focus in the treatment of key suppliers. Communication and teamwork between the prime contractor and key GFP suppliers must be effective and continuous. To facilitate communication in areas such as interface requirements, changes in design, risks, and schedules, the Government must assure that its contracts with key GFP suppliers and the prime allow Associate Contractor Agreements (ACAs). Use ACAs when contractors working on separate government contracts must cooperate, share resources or otherwise jointly participate in working on contracts or projects. Tailor each Associate Contractor Agreement (ACA) to the requirements of the individual contracting situation.

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 is implemented on a program, the agreement must provide for the participation of key GFP contractors in IPPD arrangements and must allow adequate insight into key GFP contractor activities so they can be fully integrated into the Integrated Master Plan (IMP). 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.

6.4.4 Key Suppliers 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. The supplier base was often neglected until the design was formalized, resulting in requirements unmatched by supplier product and process capabilities. System integration has often been hampered by interface difficulties indicating ineffective prime/supplier communication, and the prime contractor has often had 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 were often overly optimistic without margin for delays.

Slips in delivery and integration problems have often hampered past programs when requirements and interfaces have not been effectively communicated to the key GFP supplier. GFP Contractor requirements were not kept current with the Prime contractor's system design.

Inadequate supplier risk assessment tools hindered risk identification and subsequent mitigation planning.

6.5 Key Characteristics and Processes

6.5.1 Introduction

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: (1) identify product characteristics of the design which most influence fit, performance or reliability; (2) support the mapping of product characteristics to production processes; (3) enable the balancing of product design requirements with manufacturing process capabilities; and (4) enable the development of the required process controls for production.

Key Characteristic (KC) definition:

A feature of a material, part, assembly, or system in which variation from nominal has the most adverse impact on fit, performance, reliability, or cost of the part.

Identification of KCs should ideally begin in the earliest phases of development, with the list of KCs continuing to be refined throughout development.

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 us to focus scarce resources on the most critical features and processes.

Early in development, the list of preliminary KCs identified in the previous phase should mature to a final list. As KC identification is 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.

6.5.2 Key Characteristics and Processes Rationale

The practice of identifying KCs serves many purposes. Among them:

- 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 IPTs as well as among prime contractors and suppliers.
- Identifying characteristics to be redesigned or eliminated in order to achieve a more robust product design.
- Identifying characteristics for which manufacturing process capabilities must be assessed.
- Identifying candidate key characteristics for future variability reduction activities.
- 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.
- Assist in selection of suppliers that already have process control in place for the processes that are high contributors to product variation.

6.5.3 Key Characteristics and Processes Guidance

Identification of KCs: Contractors have used a wide spectrum 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.

Critical Safety Items (CSIs):

Key Characteristics should be used to control the quality of parts designated as Critical Safety Items.

By definition, there should be relatively few KCs. Although there is no magic number that is universally applicable, each part may have 1-3 KCs, and most simple parts (such

as clips and brackets) should have none. Once identified, KC status is not etched in stone. They are changeable over time and may be deleted as the design is changed. New KCs may also be added as the design is refined. If KCs are identified for assembly characteristics (such as fit, gaps, etc.), then the design for piece parts composing the assembly must be assessed to determine if KCs exist at the lower part/assembly level. If KCs are identified for assembly characteristics (like an overall dimension across three parts), then the design for each piece part composing the assembly must be assessed to determine if KCs exist at the lower part/assembly level. On a very weight sensitive assembly, weight could be a KC for the individual parts within that assembly. Through this approach, higher level KCs may be flowed down to the lowest possible level to assure controls in fabrication.

A common question that arises is, “Should KCs be deleted when the manufacturing process is highly capable?” By definition, the status, 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.

KCs should be identified on drawings or in specifications. One method is to use a flag, as shown in Figure 6-2, which depicts 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.

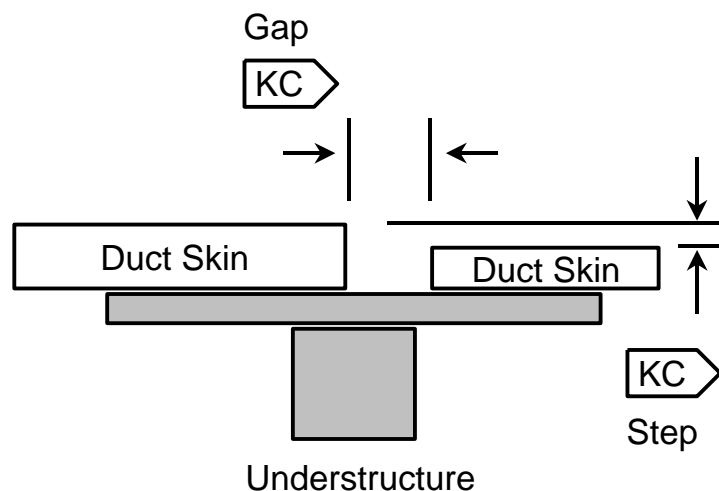


Figure 6-2. KC Flags on Drawings

Figure 6-1 shows a standard nomenclature that may be used when discussing key product characteristics. It also demonstrates how identification of key characteristics can begin at

the highest level of user needs and then flow down to the lowest possible level of process control.

Mapping of 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.

Suppliers: 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 systematic plan for managing their suppliers' production of designs and products with key characteristics.

Often the question 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 there are examples of both from various companies.

Additional guidance on key characteristics can be found in AS9103, "Variation Management of Key Characteristics."

6.5.4 Key Characteristics and Processes Lessons Learned

The benefits gained from improved communication and coordination among disparate organizations as a result of identifying KCs cannot be overstated. The process of having cross-functional (and often cross-company) representatives at the same table to determine critical interfaces, features, etc. can pay huge dividends. In a major airframe program, this coordination resulted in major structural sections fitting "like a glove," despite being designed and built by different companies, geographically separated, utilizing 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: (1) misunderstanding of the definition of KCs; (2) overly cautious product design engineers who see KCs as an opportunity to tighten the reins on manufacturing; and (3) the desire for manufacturing data. 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 (which they should have gotten through other means). 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 judiciously, 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 Independent Review Team 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.

6.6 Variability Reduction

6.6.1 Introduction

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: (1) develop control plans for critical processes; (2) begin data collection on key processes to determine process capabilities; (3) feed these process capabilities back to the designers; and (4) implement improvements in the design and/or manufacturing processes, as required.

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.

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.

Production phase VR efforts fall into four areas: (1) data collection during production operations to monitor process performance and initiate preventive actions; (2) the implementation of process improvements during build activities; (3) assessment of feedback received from field users and support personnel, and field reliability data; and (4) implementation of design enhancements to improve performance, producibility, and affordability.

6.6.2 Variability Reduction Rationale

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 the Taguchi Loss Function (shown in Figure 6-3), 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 further away from nominal, the higher the loss. The logical solution, therefore, is to reduce the amount of variability by centering the process output as tightly as possible on the nominal specification value.

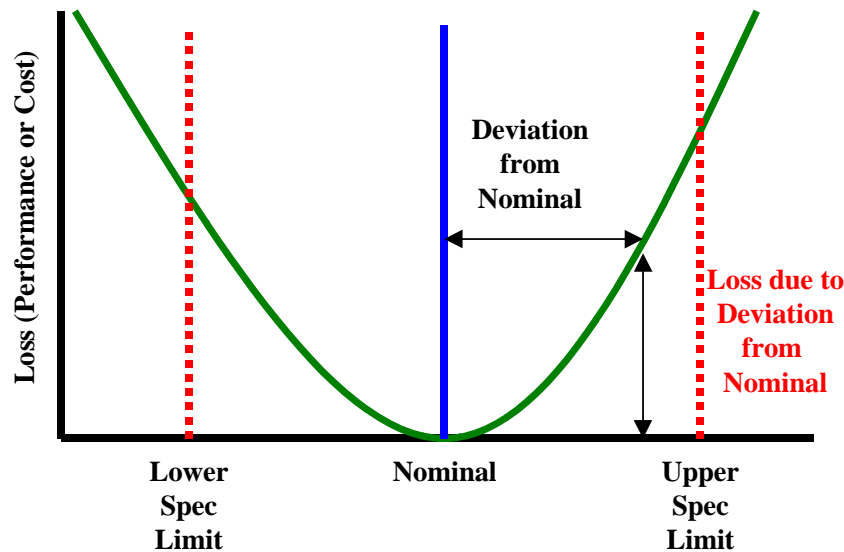


Figure 6-3. The Taguchi Loss Function

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

- Quality improvement in the form of better fit, performance, and reliability
- Cost savings from reduced assembly hours
- Cost reduction due to reduced scrap, rework, and repair
- 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
- Reduced reliance on end-item inspections to detect nonconformance resulting in reduced inspection cost
- Customer satisfaction due to increased service life

6.6.3 Variability Reduction Guidance

Figure 6-4 shows the sequence of activities for a Variability Reduction Program.

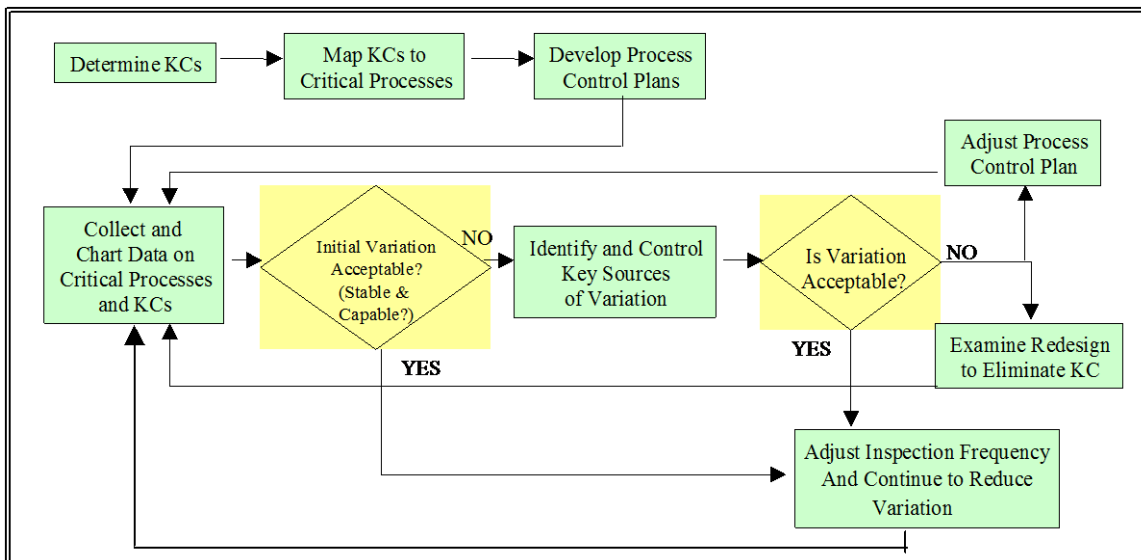


Figure 6-4. VR General Approach

Determine KCs: Two aspects of variability reduction affect the design of characteristics that have been identified as key. First, 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. Second, 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.

Develop Process Control Plans: For each critical process related to a KC, the contractor should document plans to control the process to assure 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. Process control plans should be considered dynamic and the IPT should adjust them periodically to account for changes in process capability.

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.

Is the Initial Variation Acceptable? To determine acceptability, the process capability index (Cpk) must first be calculated using the following formula:

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

Where:

USL = Upper Specification Limit

LSL = Lower Specification Limit

Avg = process mean

3σ = 3 times the process standard deviation

Note: The above formula and the following discussions 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 (roundness of a bearing, for example, where “0.0” out-of-round is optimal and there is a maximum allowable deviation from “0.0”), please refer to statistical texts for correct the formula and analysis assistance.

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 in Figure 6-5. A Cpk of 1.5 is equivalent to 6.8 defects per million opportunities, and represents a commonly encountered VR standard. A Cpk of less than 1.00 corresponds to a defect rate greater

than three per thousand. It is usually indicative of an immature or incapable process that requires additional development, a design change, or added process verifications to assure conforming product is delivered. Acceptability should be determined by the IPT based on statistically sound data, considering impacts on producibility, cost, and quality considerations.

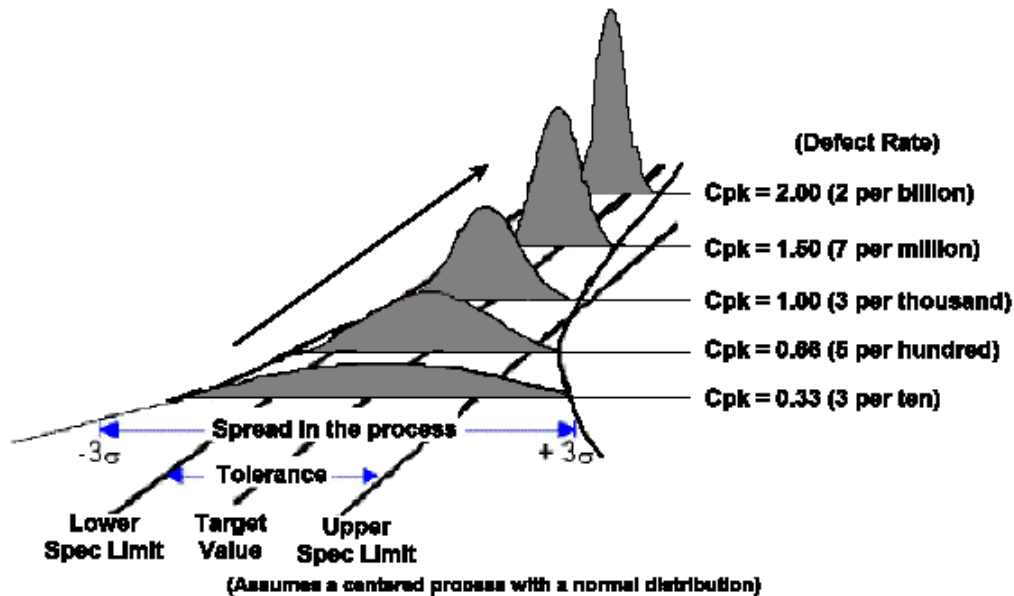


Figure 6-5. Capability Index

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 charting to monitor and accept products and to assure 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 assure the process control plans are effective.

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. It may include variation introduced by tooling, machine programming, drill bit wear, etc. 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). 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. Common cause variation can lead to modifications to the process and flowcharting these process improvements before implementing them increases the probability they will be successful without introducing unexpected side-effects.

Is Variation Acceptable? 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:

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). This is the same option discussed in the “Determine KCs” paragraph above. Redesigning to open tolerances is a first option considered while the design is in development and a last option after we’ve tried everything else to make an existing process capable. In design development, tolerances should be set as loose 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.

Adjust Process Control Plan: If process variation is still not acceptable, additional controls may have to be added (such as inspection) to assure 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. If every item is inspected, there is still a probability that some unacceptable product will be accepted. The best solution is to avoid production of unacceptable product.

Additional guidance on key characteristics can be found in AS9103, “Variation Management of Key Characteristics.”

6.6.4 Variability Reduction 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 assure conforming product. However, metrics are extremely important to assess the overall progress towards achieving process maturity and capability.

Although there are almost as many ways to do Variability Reduction as there are contractors and subcontractors, the principles of each methodology should germinate from the goal to reduce quality cost 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 you are trying to control 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.

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 that does the necessary calculations for you. While these tools bring a powerful capability to the uninitiated for garnering meaning from raw data, they also bring an unlimited opportunity for misapplication and confusion. Don't assume that because a computer statistical package can take some data and give you an answer, that it is the right answer. There is one statistical principle that needs to be honored: Don't use data that you don't understand (Where did it come from? Is it normally distributed?)

6.7 Virtual Manufacturing

6.7.1 Introduction

Virtual manufacturing is an integrated, synthetic (computer generated, not producing real physical hardware) manufacturing approach. It uses modeling and simulation to address 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 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, virtual manufacturing 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.

Production activity and the cost associated with manufacturing is generally expected to decrease over time due to ongoing improvements in production methods and the experience gained by personnel directly involved in production as they repeat assembly tasks. This phenomenon is called "Learning" and its effects are widely studied and well documented. Virtual Manufacturing accelerates learning by achieving much of the methods improvement anticipated to occur during production before the first unit is assembled. It also accelerates the realization of the experience element of learning if the

virtual models are used as training tools for production personnel. The virtual tools let the producer begin production at a lower T1 cost, in effect, skipping much of the inefficiency common early in production.

Virtual Manufacturing also plays a role in the concept of the “Virtual Enterprise.” In a Virtual Enterprise, critical manufacturing related information is communicated across barriers between organizations (business to business). A Virtual Enterprise consists of any number of geographically separate but virtually collocated teams of companies and government organizations, representing the best world-wide capabilities available at the time, independent of organizational affiliation, working together electronically at least as efficiently as a fully collocated team within one company or organization. If this Virtual Enterprise has a manufacturing element to its operation it will likely be virtual as well. The simulated capabilities of a particular supplier’s production processes can influence the design regardless of the distance separating the system designer and manufacturer. The manufacturer has the same advantages regarding easy access to the designer during production. Regardless of physical distance between the cooperating entities, virtual manufacturing allows for the ultimate efficiency possible in all production phases, including selection of sources, development of Numerical Control data, fabrication of components, assembly of systems, and delivery of products.

Product design iterations in a virtual manufacturing 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. So, virtual tools hold great potential for reversing current trends toward longer and longer development cycles. For these reasons, virtual manufacturing is becoming an increasingly common alternative or supplement to traditional means of demonstrating factory capabilities, such as Line Proofing (See Product and Process Validation).

Like line proofing, virtual manufacturing supports risk management activities by verifying and validating the capabilities of the production facilities. Unlike line proofing, virtual manufacturing 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 more cheaply.

Stereolithography is another rapid prototyping tool that can provide sub-scale or full-scale physical models directly from CAD designs and the models can be used for assembly process demonstrations early in the design process. It provides some of the benefits of physical mock-ups at a lower cost.

Virtual manufacturing techniques also enable the manufacturing engineer to effectively demonstrate manufacturing issues to the IPT. Because virtual manufacturing and virtual prototyping capabilities allow the integrated product team to validate its product design and production processes in a synthetic environment, the IPT can evaluate the performance characteristics of a greater variety of product configurations. They can make truly effective cost and performance trades at the earliest stages of development. The result is an initial production unit that meets performance objectives with almost no rework and at the lowest possible cost.

6.7.2 Virtual Manufacturing Rationale

The virtual manufacturing and virtual prototyping process includes new tools for assembly simulation, process flow simulation, and numerically controlled machine tool simulation. These are integrated with CAD tools, MRP, scheduling tools, time standards, work instructions, and planning. Virtual manufacturing activity starts with the development of a virtual prototype, and continues through the design and first unit planning phases to create a digital manufacturing plan. Addressing issues from layout of the production plant to electronic interaction with the supplier base, the digital manufacturing plan provides a solid foundation for manufacturing control protocols.

The benefits of virtual manufacturing include:

- Ability to quickly evolve the development product and process design in a synthetic environment where changes can be made early and cost effectively.
- Ability to increase design iterations while decreasing physical iterations.
- Improved communication and cohesion between Integrated Product Team participants during product development, with virtual design and virtual manufacturing models as a common visual reference point.
- Assurance of optimum first time results for prototypes.
- Readily available common basis for manufacturing planning and cost estimating.
- Enhanced LRIP efficiency and facilitates ramp up to full production.
- Reduced risk of transition to production.
- Reduced unit cost through the avoidance of rework.
- Reduced T1 labor costs.
- Reduced sustaining engineering effort.
- Reduced production cycle time and verification of production tooling concepts.
- Simulations that are usable for developing operator work instructions and maintenance tasks.

Virtual manufacturing makes it possible to effectively realize the full benefits of Integrated Product Development and manufacturing's early involvement to influence design quality, producibility, and affordability. The advent of virtual manufacturing and

its linkage to the design model has made it easier for the manufacturing engineer to decipher the true impact of each design iteration, and to get his message across to other members of the design team. Now manufacturing engineering can be fully integrated into the product design effort with virtual tools that help identify and explain the impacts of the design on producibility using data and visual models that will be understood outside the manufacturing arena.

6.7.3 Virtual Manufacturing Guidance

The contractor should use virtual manufacturing tools to demonstrate that the product design developed during the early development phase efforts meets the cost and schedule objectives of the program. This is best accomplished through preliminary production planning, which includes assembly simulation and process flow simulation, utilizing the processes required for fabrication. On the contractor's side, these efforts are frequently led by the manufacturing engineering function during the early phases. The contractor should also demonstrate the producibility of the proposed design through the use of virtual prototyping and virtual assembly, including 3D simulation of assembly for both the product and its proposed tooling. This permits qualification of production cost and schedule risks tied to the design as soon as design options are developed and before resources are committed.

Process flow simulation should identify the production resources required, including personnel skills, tool quantities, production space requirements, inventory levels, and resource constraints. This effort will serve to validate cost estimates and proposed schedule performance. It will also identify issues associated with material availability or new process development. The simulation tools thus provide a quantitative and analytical basis for the participation of the manufacturing engineer in the IPT process.

6.7.4 Virtual Manufacturing 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 virtual manufacturing 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, for instance, demonstrated the benefits of virtual manufacturing by comparing results to those of parallel activities using IPPD practices without VM. The design cycle time was reduced by 33%, and design cost was reduced by 27%. Another program, this one contractor funded, used solid modeling, parametric design, and virtual manufacturing 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.

The ability to approach or exceed the benefits achieved in the preceding examples depends largely on two factors: the phase of the program in which the virtual manufacturing effort is initiated, and the consideration given to a system wide application of the virtual manufacturing tools. All of the examples provided demonstrate implementation during some intermediate step in the development process. It is expected that when these tools are applied to their maximum capability very early, as is the case with programs like JSF, the savings should be even more remarkable. Until recently, it was common belief that there would not be a sufficient payback to develop the data for virtual manufacturing after a program has completed preliminary design. In many of the examples provided, the application of one or more virtual manufacturing tool resulted in minimal near term payback, until the application was expanded to include down-stream organizations that could make use of the data to improve their efficiency. It is recommended that a global view be taken when implementing virtual manufacturing, giving consideration to commonality of tools across an enterprise, including portability of software and data.

6.8 Design Trade Studies

6.8.1 Introduction

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. Any system design concept, or production concept, will have risks associated with its development or implementation. Design and production risks often relate to the producibility, supportability, and maintainability attributes of the system. Design trade studies provide a systematic way to mitigate risks that cannot be eliminated.

Trades involve iterative comparisons of cost and performance of alternatives, not simply a single trade analysis on initial performance requirements. Interaction of relevant design factors is usually complex and there is rarely a single point solution, so trade studies should continue throughout system development, production, and support. Systems engineering can be generalized as a series of processes where design trade studies are routinely performed to support iterative design improvements. During Requirements Analysis, requirements are traded against each other and against cost. Later, in Functional Allocation, functions are balanced against interface requirements and performance. In Design Synthesis, alternate solutions are evaluated to optimize cost, schedule, performance and risk (e.g. trading off the performance benefit of using high temperature materials against added cost and producibility risk.) The systems engineering trade study process employed should use a coordinated production cost model wherever possible and trade studies must be part of the corporate design policy and process.

6.8.2 Design Trade Studies Rationale

Institutionalizing producibility as part of the systems engineering design trade study process is essential to an overall goal of affordable weapon system acquisition. The

development of a reliable production cost model and manufacturing engineering participation in the IPT make it possible to use the Production Cost Requirement, normally either the Average Unit Production Price (AUPP) or Design-To-Unit Production Cost (DTUPC), as the primary design trade parameter. However, not all design trade considerations can be restated in terms of their impact on unit acquisition price. Downstream costs associated with operation, maintenance, and disposal of the system are often locked in early in design, and these elements must be considered when we are searching for the optimum trade solution. Consequently, Life Cycle Cost (LCC) has become a common parameter. Participation of both the government customer and key suppliers in the product IPTs and the trade study process assures a fully integrated design effort more apt to meet customer's needs and one which minimizes life cycle cost. Improved communications between engineering and manufacturing personnel and between prime contractor and suppliers help to reduce integration problems that compromise system performance or which results in redesign of one or more components.

Acquisition reform has expanded the options available to design and manufacturing engineers. The freedom to use commercial or contractor-defined and controlled processes gives the designer the flexibility to propose a system design that takes maximum advantage of the most appropriate capabilities.

6.8.3 Design Trade Studies Guidance

Careful consideration of producibility is key to the Integrated Product and Process Development (IPPD) concept. 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.

The effectiveness of design trade studies depends on an accurate description of the problem prompting the study, and the establishment of specific criteria for making a decision. 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 dependant on the relative contribution of each concept to achieving the Production Cost Requirement (see figure 6-6 below). 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.

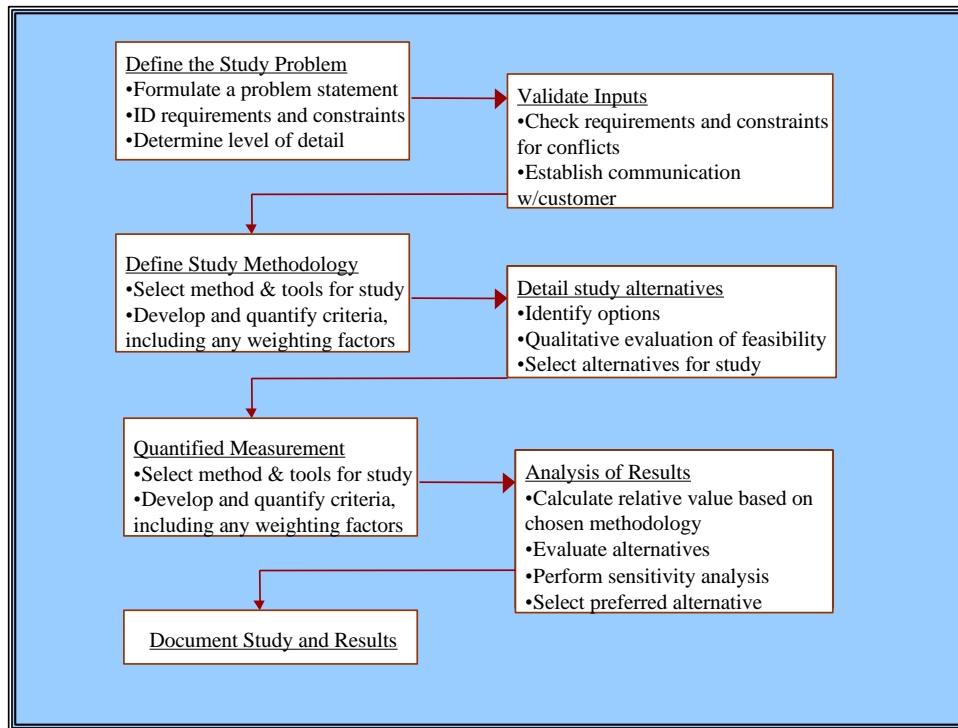


Figure 6-6 Trade Study Process

There is considerable flexibility regarding the level of detail reached in a trade study, with the degree of cost and schedule risk a controlling factor. Since the analysis is time-critical, ensure that design trade study procedures establish a specific schedule for completion, identify individuals responsible, and define a proper level of reporting prior to Critical Design Reviews.

Trade studies should encompass the product design, production processes, Special Tooling, Special Test Equipment, and Support Equipment (ST/STE/SE). Mandated performance requirements ("must haves") provided in the System Specification form the baseline. However, design margins should still be identified for each of the items in the System Specification. The contractor should have the flexibility to address how much margin is applied within program cost and schedule constraints. Additional capabilities above the individual requirements may be found within the total system constraints, and the contractor should be encouraged to identify opportunities for improved capabilities.

Widely accepted techniques for performing trade studies can be found in Systems Engineering guides, such as Systems Engineering Fundamentals published by DSMC, available at http://www.dau.mil/pubs/gdbks/sys_eng_fund.asp.

6.8.4 Design Trade Studies Lessons Learned

Two functions related to design trade studies have been the source of difficulties in the past: design for production and effective communication between primes and suppliers. Past efforts have relied on a serial development effort between product and process. During pre-Production, virtually all development emphasis was placed on system

performance. Once the required performance was functionally demonstrated, an attempt was made to transition the design to production. The manufacturing engineering function then tried to adapt existing processes to manufacture the "qualified" design. The result was a sub-optimal design from two respects: (1) little or no attempt was made to optimize the product design for existing process capabilities; and (2) new or improved processes received little consideration. Considering producibility earlier in the design process promises a smoother transition to production. Reaching rate production should also be easier and more efficient as processes are continuously improved.

Weapon systems' functional allocation and initial designs have often been completed with little or no participation from key suppliers. The prime contractor/supplier relationship has been primarily controlled by product requirements defined in specifications, drawings, and interface control documents. Since suppliers frequently had little understanding of how the product was actually to be used, their design would often meet all performance requirements; yet not successfully integrate into the weapon system. The result was a series of redesigns or compromises in overall design quality. An early integration of key suppliers into the prime contractor's design team enhances the ability to transmit actual requirements and to make trades for producibility at the subsystem and component levels. The experience gained by contractor personnel (at all levels) as they participate in interface control working groups will be useful as they adapt to the operating philosophy of joint IPTs.

6.9 Process Failure Modes Effects and Criticality Analysis

6.9.1 Introduction

Process Failure Modes Effects and Criticality Analysis (PFMECA) is an engineering tool for analyzing and preventing failures in manufacturing and assembly processes. The objectives of this practice are: (1) identify the potential failure modes of a process and the effects of those failures; and (2) develop actions that will mitigate or eliminate the probability of the potential failures.

The PFMECA is a process design tool, and should be performed iteratively from conceptual design through development. It is used to identify potential failure modes before they are incorporated into a process. The timeliness of the analysis is important because alterations to the process in the design phase are easily implemented, while late corrections to a manufacturing process may involve higher cost and the risk of complications.

6.9.2 FMECA Rationale

Conducting a PFMECA during the process development permits early problem identification and resolution. This technique focuses on prevention of nonconformance rather than detection. A thorough application of the PFMECA 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 the design phase. Failure modes that cannot be entirely resolved can be recognized and mitigated. By reducing failure points and thereby increasing process quality, we should be able to reduce production, operational and maintenance costs, as well as injuries. The Air Force and suppliers should realize the following benefits:

- Increased quality because of a more thoroughly engineered manufacturing process
- Cost savings by reduction of rework
- Cost reduction by identification of potential errors earlier in the life of the system
- Understanding of the effects of potential failures on the customer
- Development of a prioritized list of potential failure modes

6.9.3 PFMECA Guidance

The PFMECA is an essential task in process design. It is intended to be performed in concert with other modern design techniques, including Failure Modes Effects and Criticality Analysis (FMECA) for products and production machinery. A PFMECA should be performed when 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 PFMECA should be thoughtfully tailored to each application. An Ishikawa diagram (also called a fishbone diagram) may be useful for some steps in the PFMECA.

A worksheet is useful for tracking the PFMECA process. An example worksheet is included in figure 6-X. The ten steps in the worksheet are described below:

1. Process Function

This is a concise statement of the function of the manufacturing process (e.g., polishing, deburring, drilling or assembling). Supporting information should be included to put the process function into context. Include the local function and function in relation to interfacing processes. Indicate the purpose of the process and include metrics for performance. Interpret the purpose of the process from the point of view of the customer, who may include the end user, downstream manufacturing or assembly operation, service operation, or government regulation.

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 (e.g., 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 (can not assemble, damages equipment, causes excessive tool wear, endangers operator). For downstream manufacturing operations, failure effects should be stated in terms of process performance. The descriptors for local effects and effects within manufacturing will be similar. 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 (e.g., 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 PFMECA team should agree on ranking criteria appropriate to the analysis. The ranking criteria should create categories of failure effects (e.g., minor, marginal, critical and catastrophic). The categories are then numbered, and a numerical rank assigned to each failure effect. Further guidance on this topic can be found with industry recommended practices, shown in the PFMECA section of Appendix VII: Reference Material.

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 (e.g., Inaccurate gauging, worn locator, improper heat treating, inadequate lubrication). Avoid ambiguous naming of causes (e.g., operator error, machine malfunction). If a cause has a direct relationship to the failure mode, then this section of the PFMECA is trivial. Causes will often be inter-related, and a design of experiments or similar method will 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. These controls prevent or reduce the occurrence

of failure causes or failures. Detection controls indicate the presence of a failure cause or failure. They 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):

$$\text{RPN} = \text{S} \times \text{O} \times \text{D}$$

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. The RPN is a subjective value because it is based on subjective measures of severity, occurrence and detection. Therefore it is not appropriate to compare RPNs between PFMECA analyses.

10. Recommended Actions

Actions should be developed with the purpose of lowering the RPNs. Recommended actions should first address high RPNs or issues that the team recognizes as important. 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.

External Guidance

Military standard methods for conducting a Failure Modes, Effects and Criticality Analysis (FMECA) are detailed in MIL-STD 1629A. This MIL-STD was cancelled on August 4, 1998. The cancellation gave guidance to “consult various national and international documents for information regarding failure mode, effects, and criticality analysis.” The standard is written for product FMECA, and no guidance is given 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. Copies of SAE J1739 are available at www.sae.org.

6.9.4 FMECA Lessons Learned

To be effective, the application of PFMECA must correspond with the nature of the process itself, and ultimately each PFMECA is a uniquely performed analysis. Because it contains subjective measurements, it is not appropriate to compare the results of different PFMECAs, 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 PFMECA is treated as a box checking, CDRL fulfilling exercise it will be of little use.

There are seven likely deficiencies in contractor performed PFMECA. They should be recognized as such and given careful consideration. They are listed below:

Untimely Undertaking: The PFMECA must be scheduled and completed concurrently with the design of the manufacturing and assembly process so that the designs will reflect its analysis, conclusions and recommendations.

Insufficient Recognition of Failures and Causes: The discovery of failures and their causes is essential to the PFMECA task. Potential failure modes must be explained, and not simply named. Ensure that 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.

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

Too Narrow a 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.

Lack of Recommendations: A common pitfall is a failure to develop recommended actions, or to develop actions that are neither actionable nor executable.

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.

Existing System's Data: Failure data and history of very similar systems should be considered.

PFMECAs can be used to identify opportunities for mistake-proofing (Poka Yoke) of manufacturing processes. Foreseeable modes of failure with high Risk Priority Numbers should, as part of their recommended actions, include mistake-proofing devices or processes. A recent Independent Review Team found that mistake-proofing is an under-utilized approach and even a moderate implementation of its concepts would have prevented several high-profile weapon system failures.

6.10 Product and Process Validation

6.10.1 Introduction

Today's acquisition environment emphasizes the demonstration of producibility and manufacturing capabilities at each major program milestone, beginning very 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 pre-determined 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). Process validation may be accomplished through line proofing, virtual modeling and simulations of the production processes, or a combination of the two methods.

6.10.2 Product and Process Validation Rationale

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 assure 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.

6.10.3 Product and Process Validation Guidance

The Federal Acquisition Regulations (Subpart 9.3) require programs to consider the implementation of First Article Testing. First articles may be appropriate when:

- The manufacturer has not previously built the product
- The manufacturer has built the product, but the design has changed, the processes or facility have changed, or production has been discontinued for an extended period of time.

First Article Inspections involve a thorough, detailed inspection of the product, including the conduct of all planned in-process and acceptance testing. It also includes auditing the process specifications, work instructions, inspection instructions, and test procedures to assure they all consistently reflect the engineering drawing requirements.

For process validation, line proofing has traditionally been the preferred means of demonstrating factory capabilities, using actual production tooling and a first set of parts to build an actual product or product component late in the development phase. The

decision to implement line proofing should be based on a manufacturing risk assessment and may include factors such as process maturity, ST/STE challenges, extent to which production processes were already used during development, and the cost of the required line proofing assets.

Line proofing serves a number of important purposes: verifying the final build-to package; verifying the capability of ST/STE; testing factory operations; verifying fault detection capabilities; and providing the systems integration and test experience required to produce the end product. A structured line proofing approach also allows iterative build, test, analysis, and improvement cycles to affect the design and build processes.

The manufacturer should document the line proofing plan and procedures. The plan should specify a sufficient number of replicate process runs to demonstrate reproducibility and provide an accurate measure of variability among successive runs. The test conditions should encompass upper and lower processing limits and circumstances, especially for those process characteristics which pose the greatest risk to key product characteristics. Key process and product characteristics should be monitored and analyzed to determine process capabilities. If, during line proofing, the processes produce nonconforming hardware, the root causes must be identified, corrections made, and additional test runs performed to verify the effectiveness of the fix.

The development of newer, more effective virtual manufacturing and assembly tools now makes it possible to accomplish many of the process validation objectives once provided by line proofing earlier and cheaper. Manufacturing simulations can achieve many of the same objectives without expending all the resources traditionally required by the use of actual production tooling and parts. A structured approach to incremental verification using virtual manufacturing tools makes it possible to check and verify the entire production process and the supporting infrastructure, thus reducing first unit rework and some of the classic transition-to-production problems.

Determining if a process like line proofing is called for in today's acquisition environment requires an analysis of the extent to which virtual manufacturing tools can simulate actual manufacturing processes and infrastructure. A mixture of virtual tools and formal line proofing may provide the optimum solution.

6.10.4 Product and Process Validation Lessons Learned

Since First Article Inspections 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 assure they are still aligned with the drawing requirements.

Line proofing can become extremely costly, depending upon the complexity of each unit, the price of raw materials and purchased parts, and the number of assets required. Therefore, the line proofing plan should be discussed early to develop a cost-effective approach and enable the program to budget for the effort.

6.11 Manufacturing Process Control and Continuous Improvement

6.11.1 Introduction

During the production phase of a weapon system program, the responsibility of the manufacturing engineering function is to focus on the effective control of the manufacturing processes and on the orderly incorporation of improvements in both product and process. As used here, the term "continuous improvement" refers not so much to improvements themselves, as to the development and implementation of tools and techniques for continuously improving manufacturing processes. Among them:

- Identifying and implementing improvement opportunities in all process areas.
- Establishing a culture in which all employees will be constantly seeking opportunities to make improvements in the tasks they perform and in the ways they perform them.

In today's acquisition environment, contracts should be structured to provide incentives for continuous production phase improvements, desired schedule performance, enhanced affordability, reduced acquisition cost, and enhanced supportability.

6.11.2 Manufacturing Process Control and Continuous Improvement Rationale

Many manufacturing problems plaguing DoD programs are caused by the lack of effective, systematic process controls during production and the absence of clear incentives for reducing costs during production. Even when development and design are complete, improvement opportunities are still available to those who are trained to look for them. Lessons learned from development testing and the initial production units may point to a need for significant modifications to the design. In addition, quality metrics from the field and from the factory may identify areas that need improvement. Also, shop floor workers are almost always a great source of creative ideas for process enhancements.

6.11.3 Manufacturing Process Control and Continuous Improvement Guidance

In the Production phase the product IPT changes its focus from design and development to production, with manufacturing engineering evolving from a contributing function to a leadership function. This increasing focus on production should ensure effective control of manufacturing processes during production and widespread use of continuous improvement methods.

A key tenet of quality programs is that production operations must take place under controlled conditions. A primary tool for process control is SPC. SPC should be applied in conjunction with a Variability Reduction program to control the critical manufacturing processes that create Key Characteristics. Other methods to assure controlled conditions include training programs, operator certifications, documented work instructions, automation, and process audits. Although inspections may be used as a control over processes, the preferable approaches are those that prevent nonconformances in the first place as opposed to merely identifying them after they occur.

The contract should provide incentives for identifying and making any additional performance or affordability improvements in the design or in processes and production methods. These incentives may include award fees, value engineering clauses, incentives for achieving target price curves, or separate Statement of Work tasks and funding for cost improvement initiatives.

Under performance-based acquisition, the contractor has primary control of the detail design and the manufacturing processes. Contractors are responsible for managing their processes, their metrics, and their continuous improvement efforts. In this environment, when an improvement opportunity is identified, the contractor has authority to go directly to the process to make corrections, changes, and improvements without requesting government approval. With this authority comes an additional obligation: contractors must be responsible for any changes they make and must, therefore, maintain an effective configuration control system to document those changes.

A number of effective techniques related to continuous improvement are available, including Value Stream Mapping, Kaizen events, Six Sigma, and the Lean Aerospace Initiative. Additional information on these subjects is readily available from many sources.

6.11.4 Manufacturing Process Control and Continuous Improvement Lessons Learned

Some manufacturers in the aerospace industry avoid using SPC because of the low quantities of many DoD programs because of the belief that it is only applicable to large production runs. However, there are many Short Run SPC techniques developed by Davis Bothe and the International Quality Institute. Even with a single aircraft, 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.

Contractual incentives for continuous improvement are absolutely essential. The only factors more potent for motivating continuous improvement are a corporate culture that already exists that emphasizes continuous improvement or a situation where the very survival of the program is at stake. In the absence of these factors, significant continuous improvement will not occur.

6.12 Factory Efficiency (Lean Factory)

6.12.1 Introduction

Historically, discussions of factory efficiency concentrated on the measurement of individual worker performance and efficiency. Although these activities are still important, in today's austere acquisition environment, achieving factory efficiency implies the continuous application in the production facility of all appropriate lean manufacturing practices and high performance manufacturing systems. It also implies a dedication to continuous improvement practices and principals during production. The ultimate objective of factory efficiency is to achieve an effective balance between product performance and affordability. There are several proven tools to help achieve that balanced goal.

6.12.2 Factory Efficiency Rationale

Factory efficiency issues extend far beyond the confines of the factory floor. The efficiency (or lack thereof) of the production floor can have significant impacts on overall program cost and performance and will specifically affect the following areas:

- Overhead absorption – as a result of dwindling defense and related commercial business, many programs see program indirect factory cost rise as the number of programs sharing the contractor's overhead pool shrinks
- Critical mass – the need for a certain minimum production rate to efficiently produce a system; a common issue when program funds are cut and annual production quantities are reduced
- Industrial base sustainment – another consequence of the reduction in defense related business; Concern over loss of competition and, in extreme cases, the ability to acquire necessary components
- Capacity constraints – contractors have a limited flexibility to ramp up production in response to a spike in demand and the government's relative position and leverage as purchasers of that flexibility has decreased as we become a smaller percentage of total business

6.12.3 Factory Efficiency Guidance

Figure 6-7 depicts the relationship of factory efficiency efforts with other production practices. A Value Stream Analysis is critical to starting manufacturing operations with a minimum of waste. Ideally, the analysis should be performed prior to laying out a production floor and developing a manufacturing plan. Practically, however, the analysis may be performed at any point in the program.

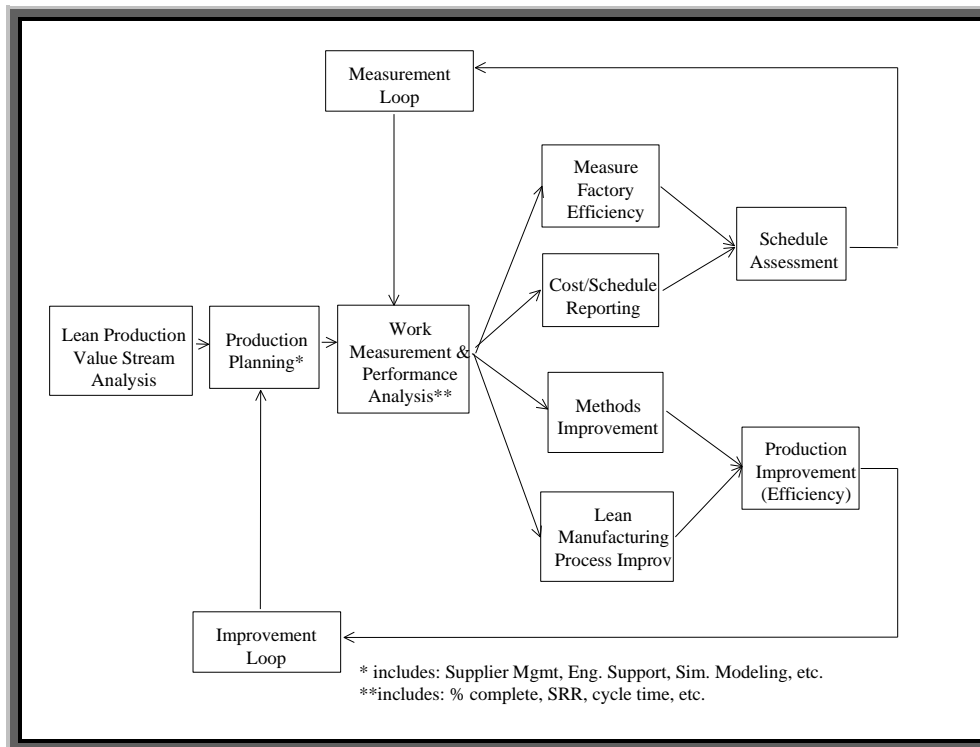


Figure 6-7. How the Factory Efficiency Practice Area Integrates with Other Practices

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. As shown in Figure 6-7, these efficiency measurements should be conducted in parallel with program schedule assessments, since they are inter-related.

The improvement of factory efficiency really means 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:

- 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.
- Single Process Initiatives (SPIs) – an initiative encouraging and facilitating the establishment of common support processes across military procurements, eliminating the need for redundant systems at contractor's facilities.
- 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.

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

To measure the progress and success in becoming more efficient, companies must select appropriate metrics. Typical metrics that are valuable for providing insight into factory efficiency include:

- Scrap, Rework and Repair: hours or dollars as a percentage of manufacturing costs.
- 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.)
- Cycle times: total duration of a task.

6.12.4 Factory Efficiency 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 Kaizen event in a given area and claim success. The Toyota Production System emphasizes continual improvement and the conduct of Kaizen events periodically in the same area. There are always opportunities to improve – they are never exhausted.

Cost Schedule Control Systems Criteria (C/SCSC) data is an important part of most program management metrics and it is often used to draw conclusions about program performance as measured in cost and schedule status. It is important that Manufacturing

and Quality Assurance personnel have a basic understanding of this data and its correlation to more detailed factory efficiency metrics. The analysis of both C/SCSC and factory efficiency data can give a complete picture, not only of where the program has been, but where it is going. If a conclusion reached in C/SCSC appears to be contradicted by other factory data the differences need to be reconciled.

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.

In an Acquisition Reform environment, submission of factory efficiency 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:

- Summary Production Schedule
- Labor Performance Data (actual hours vs. work measurement standards)
- Line of Balance (or similar status) charts
- Scrap, Rework and Repair metrics
- Supplier schedules and status

6.13 Technology Obsolescence & Diminishing Manufacturing Sources (DMS)

6.13.1 Introduction

The impact of technology obsolescence and diminishing manufacturing sources on the cost and performance of our Weapon Systems has increased exponentially 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. Moore's Law postulates that the rate of technology advancement in commercial electronics doubles integrated circuit density, speed and memory capacity every 18 months to 2 years. Complexity of manufacturing processes and the cost of production facilities has accelerated at a similar rate. Since we increasingly depend on the same integrated circuit production facilities that produce chips for PCs and a thousand other commercial items, but we buy only a fraction of the quantity, we must follow rather than lead change. The serious nature of the problem we face is evident when you consider that the typical development cycle for our systems is 5 to 8 years, and the operational demand for replacement components often extends 25 years or beyond (Figure 6-8). So from the time we define the system's

architecture until we complete production, the components that make up the system may be obsolete several times over.

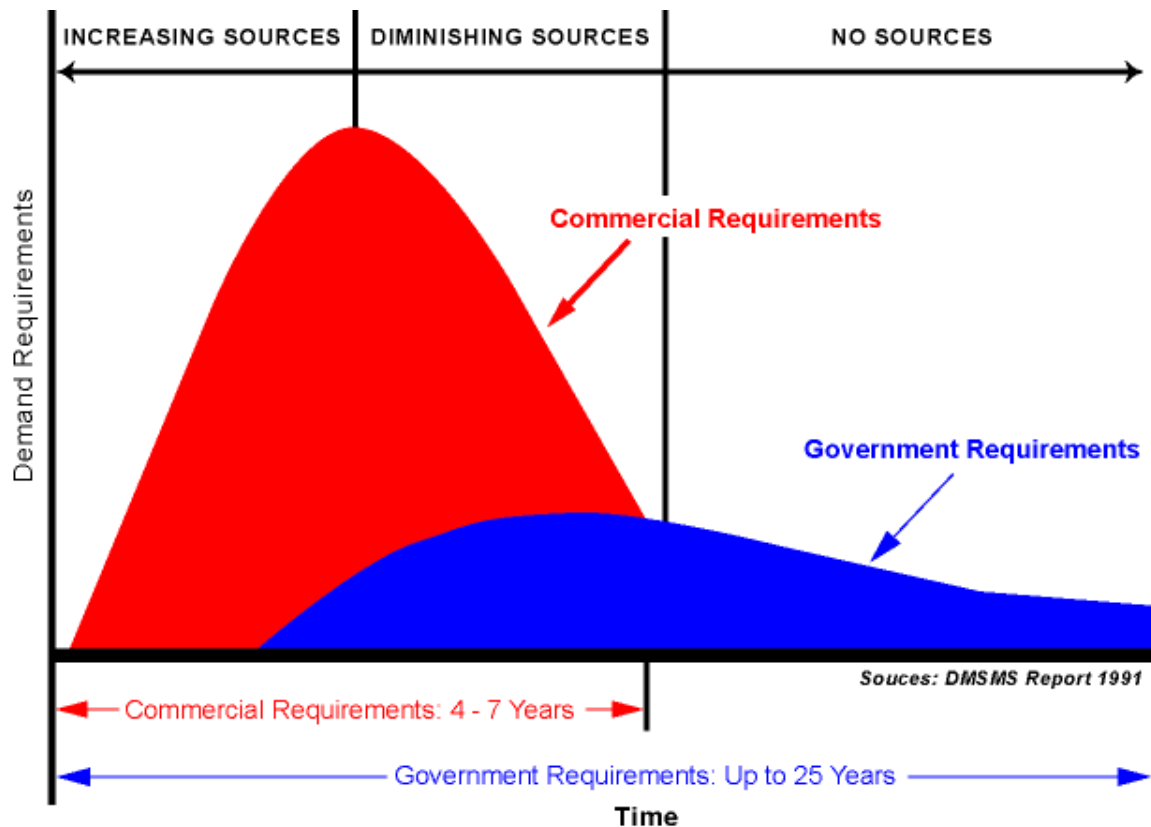


Figure 6-8. Diminishing Sources

The Defense Industry has been forced to adapt to technology obsolescence in the only way possible. Where system acquisitions previously relied on a single long rigid sequential design and development process, we are now incorporating a methodology for constant, controlled change throughout the development and operational life of our systems. This process is commonly referred to as “Evolutionary Acquisition,” and it relies on design/production cycles rather than one long development sequence. These cycles provide for regular upgrades in system capability that meet changing user needs, in parallel with system upgrades that accommodate component obsolescence.

For existing systems, caught in the wave of parts obsolescence without the advantage of a pre-planned evolutionary acquisition strategy, there are two options available. First, components that are expected to go out of production in the near future can be purchased and stored in quantities sufficient to keep the system in operation for its entire operational life, or at least until the next anticipated upgrade/redesign. This option effectively locks in the current design, with any limitations and operational shortcomings. A second, and much more expensive, option is to redesign the system when a part becomes obsolete, designing in the new technology. Unfortunately, this option increases the likelihood that another redesign will be necessary in a few years when technology changes again.

Manufacturing's roll in the acquisition lifecycle does not change radically with current steps to counter technology obsolescence. But our ability to anticipate improvements in production technology and to evaluate the costs of production plays an important roll in IPT efforts to plan for evolutionary cycles. Like the system designers, manufacturing process developers are experiencing the need to introduce greater flexibility into manufacturing processes to accommodate the changes that come with obsolescence. Electronic system developers are implementing new open designs and modular architectures that simplify and reduce the cost of upgrading to new technology. Manufacturing must also respond with general-purpose processes and tooling that minimize the time and cost to incorporate the new components into the supply chain and assembly process.

6.13.2 Technology Obsolescence & Diminishing Manufacturing Sources Rationale

When technology changes, the system's prime contractors must change their designs too, or they will be left without a source for the components we need. As a decreasing piece of the electronics sales pie (studies show the Defense Industry dropped from nearly 20% of total microcircuits in the 1970s to less than 1% today), we have little or no ability to influence the direction or rate of change in technology (figure 6-9). So it falls to the system developer to make the best use of the technology that is available, while it is available.

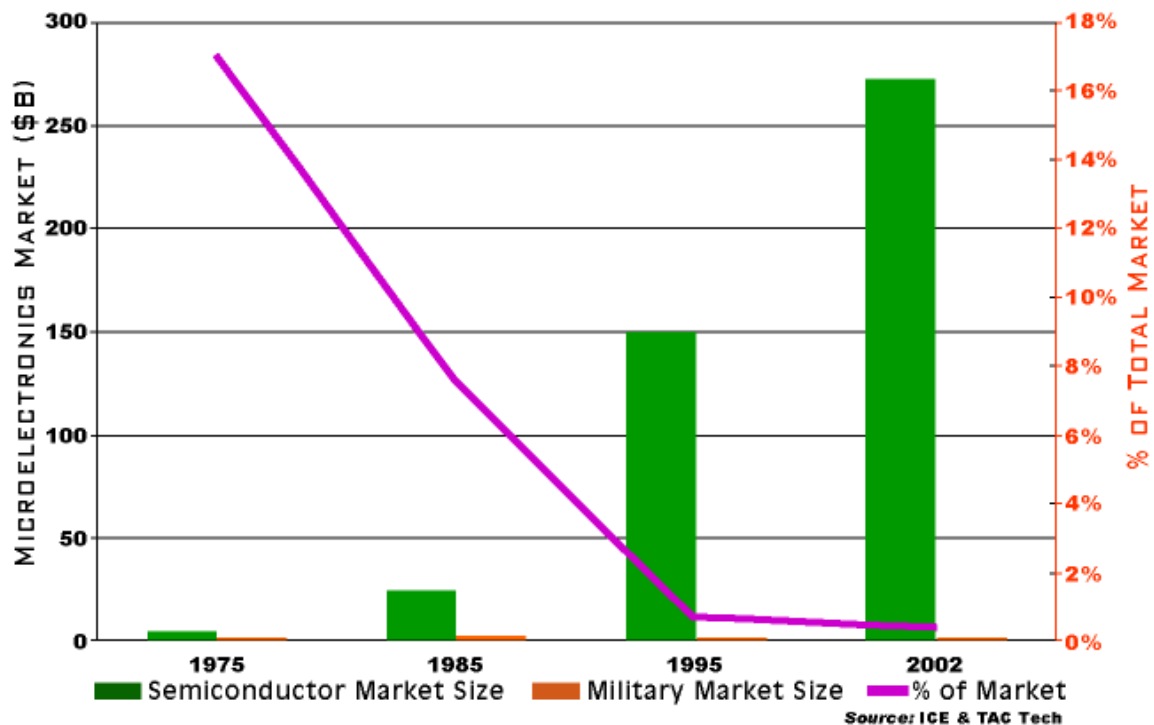


Figure 6-9. Electronics Market

Evolutionary Acquisition introduces no new solutions (the basic options are still buy out a production run or redesign to incorporate the upgrade), but it provides the advantage of planned change rather than reaction to whatever happens. Planning permits us to adapt

over a longer period of time, which is critically important in Defense Acquisition. As much as we try to reduce the time it takes to develop and field a weapon system, nothing can be done without adequate funding, and the funding process is mostly inflexible to short term change. The money to buy out a production run or redesign a system in response to changing technology requires identification of a source of funds for that activity more than two years in advance of the need date. A planned redesign/upgrade cycle, the structure behind Evolutionary Acquisition, identifies up front when the funding will be needed in time to complete the budget cycle.

6.13.3 Technology Obsolescence & Diminishing Manufacturing Sources Guidance

The importance of technology obsolescence, DMS and Evolutionary Acquisition has long been recognized by the Office of the Secretary of Defense and incorporated in the rewrite of the DoD 5000 guidance documents. Paragraph 4.3.2 of 5000.1 states “Approved, time-phased capability needs matched with available technology and resources enable evolutionary acquisition strategies. Evolutionary acquisition strategies are the preferred approach to satisfying operational needs.” Additionally, in DoD 500.2 section 3.3 Evolutionary Acquisition states “Evolutionary acquisition is the preferred DoD strategy for rapid acquisition of mature technology for the user.” And it directs; “The approaches to achieve evolutionary acquisition require collaboration between the user, tester, and developer.”

6.13.4 Technology Obsolescence & Diminishing Manufacturing Sources Lessons Learned

In some cases, commercial demand for materials or components that have historically been used only in defense systems can nearly push us 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. In the first case 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. In the second case, the explosion in the personal communication and gaming industry (e.g. Cell phones and Gameboys) 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 F-22, the JSF, and the C-17 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.

A recent development holds a lot of potential for alleviating some of the pain of electronic part obsolescence. A process called Generalized Emulation of Microcircuits (GEM) provides for a standard representation of the design of an integrated circuit,

combined with an emulation production method that copies the functions of an older out-of-production IC chip on an modern chip. If the design of the original chip was properly documented using VHSIC Hardware Definition Language (VHDL) (in this acronym VHSIC stands for Very High Speed Integrated Circuit), then emulation is a cheaper alternative to redesign. If the design in VHDL is not available, it can be created using reverse engineering, at a higher cost. Interestingly, although this process was developed under a DLA project called Advanced Microcircuit Emulation program (AME), commercial demands for the process are beginning to outstrip, and outbid, military demands.

Appendix I: MDG Acronyms

ACA	Associate Contractor Agreement
AUPP	Average Unit Production Price
CAD	Computer Aided Design
CAIV	Cost as an Independent Variable
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CE	Concept Exploration
CFP	Contractor Furnished Property
CI	Complex Item, as in a design specification
CME	Contractor Manufacturing Engineer
COTS	Commercial Off-the-Shelf
CPARS	Contractor Performance Analysis Review System
Cpk	Capability Index
CRAD	Contractor Research and Development
CRI	Cost Reduction Initiative
C/SCSC	Cost/Schedule Control Systems Criteria
CSI	Critical Safety Items
CSOW	Contractor Statement of Work
DAL	Data Accession List
DFMA	Design for Manufacturability and Assembly
DFx	Design for “x”
DMSMS	Diminishing Manufacturing Sources Material Shortage
DoD	Department of Defense
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DoDR	Department of Defense Regulation
DOE	Design of Experiments
DRFP	Draft Request for Proposal
DTC	Design to Cost
DTUPC	Design to Unit Production Cost
EMD	Engineering and Manufacturing Development
EPA	Environmental Protection Agency
FAI	First Article Inspection
FMEA	Failure Mode & Effects Analysis
GFE	Government Furnished Equipment
GFP	Government Furnished Property
HQA	Hardware Quality Audit
ICD	Interface Control Document
IMP	Integrated Master Plan
IPPD	Integrated Product and Process Development
IPT	Integrated Product Teams
IRAD	Internal Research and Development
IRM	Integrated Risk Management
JACG	Joint Aeronautical Commanders Group
KC	Key Characteristic
LCC	Life Cycle Cost
LRIP	Low Rate Initial Production
LRU	Line Replaceable Unit
MCA	Manufacturing Capability Assessment
Mfg.	Manufacturing

Manufacturing Development Guide

MDG	Manufacturing Development Guide
ME	Manufacturing Engineer
MM/PCR	Manufacturing Management/Production Capability Review
MRP	Materials Requirement Planning
MRP II	Manufacturing Resource Planning
MSE	Manufacturing Systems Engineer
NDI	Non-developmental item(s)
NDI	Non-destructive Inspection
OSS&E	Operational Safety, Suitability, and Effectiveness
PBBB	Performance Based Business Description
PBBE	Performance Based Business Environment(s)
PCM	Production Cost Model
PCR	Production Cost Requirement
PDR	Preliminary Design Review
PDRR	Program Definition and Risk Reduction
PFMECA	Process Failure Modes Effects and Criticality Analysis
PMR	Program Management Review
Pre-EMD	Pre-Engineering and Manufacturing Development
QFD	Quality Function Deployment
RAA	Required Assets Availability
RFP	Request for Proposal
ROM	Rough Order of Magnitude
RTOC	Reduction of Total Ownership Costs
SE	Support Equipment
SEMS	Systems Engineering Master Schedule
SOO	Statement of Objectives
SOW	Statement of Work
SPC	Statistical Process Control
SPI	Single Process Initiatives
SRD	System Requirements Document
SRU	Shop Replaceable Unit
SSAC	Source Selection Advisory Council
SSEB	Source Selection Evaluation Board
ST/STE	Special Tooling/Special Test Equipment
ST/STE/SE	Special Tooling/Special Test Equipment/Support Equipment
SVR	System Verification Review
T1	First unit
TBD	To Be Determined
TDP	Technical Data Package
TIM	Technical Interchange Meeting
TOC	Total Ownership Costs
TQM	Total Quality Management
VE	Value Engineering
VM	Virtual Manufacturing
VR	Variability Reduction

Manufacturing Development Guide

Appendix II: Statement of Work Inputs

MIL-HDBK-896, “Manufacturing and Quality Program,” was specifically written to contractually implement MDG practices. The handbook may be cited in all or in parts in a contract Statement of Work or Statement of Objectives (SOW/SOO). It may also be cited in Systems Engineering Plans.

It contains brief, concise descriptions of the best practices described in the MDG. These descriptions are stated in “should” terminology as is appropriate for a handbook. The handbook should be cited in a SOW or SOO with the following statement:

The contractor shall implement a Manufacturing and Quality program using MIL-HDBK-896 as a guide.

Although, as a handbook, it can only be a guide, it nevertheless serves to communicate to the contractor (or offerors) what practices the government expects them to implement to achieve a producible, affordable, conforming system.

MIL-HDBK-896 is designed to be highly tailorable, based on the needs and the phase of the program. The entire document may be called out or only applicable sections may be extracted and inserted into SOWs/SOOs.

Appendix III: Other RFP Inputs

System Specification Requirement

Production Cost. The [program name] average unit production price (AUPP) shall not exceed \$_____ in [constant FY __ dollars] for [total volume or target volume and range] production units at a maximum production rate of [average rate/specific planned rate/target rate and range] per month. (Identify and define cost elements included and/or explicitly excluded). Cost allocations for Complex Items (CIs) shall be identified in the CI Development Specifications. [The average unit production cost goal for the system is \$_____ in [constant FY __ dollars] for the same volume and rate(s)]

System Specification Verification

Production Cost. The [program name] AUPP requirement shall be verified by analysis using a joint government/contractor PCM and recognition of the current cost risk of the estimate.

Government Statement of Objectives

Quality Systems. The government's objective is that the contractor implement an overarching quality system that ensures effective execution, integration, and administration of the design, manufacturing, and deployment processes and systems needed to manage risk, ensure achievement of all performance requirements, and prevent the generation of defective product. The system should also include a means for measuring the effectiveness of and ensuring the continuous improvement of systems and processes.

Manufacturing Development. The government's objective is that the contractor implement those processes and systems that consider manufacturing, quality, and design functions in achieving a balanced product design which meets cost, schedule, and performance requirements with acceptable risk. Implement a Manufacturing and Quality program using MIL-HDBK-896 as a guide. Appropriate practices for implementation may include production cost modeling; identification of key characteristics and processes; variability reduction; electronic simulations of the manufacturing environment; cost/performance trade studies; manufacturing capability assessments; product and process validation; and key supplier relationships.

Production Quality and Manufacturing Efficiency. The government's objective is that the contractor implements those processes and systems to assure program affordability through product quality and manufacturing efficiency. The following elements may be considered as appropriate practices for implementation: product improvement initiatives; variability reduction on product and process; manufacturing process control and continuous improvement; and key supplier relationships.

Manufacturing Development Guide

Award Fee Inputs

The following are suggestions to be considered as starting points in developing award fee criteria. Each program should tailor the criteria to fit their particular circumstances, priorities, and risks.

- A manufacturing plan is available and it includes a solid approach for identifying key characteristics, critical manufacturing processes, and performing variability reduction activities and manufacturing capability assessments. The plan describes an active, aggressive producibility program.
- A quality plan is available and it describes sound plans for implementing an effective Quality Management System that focuses on defect prevention.
- A subcontract plan is available and it clearly describes implementation of a world-class supplier management organization that ensures exceptional supplier performance.
- 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.

Appendix IV: Integrated Master Plan (IMP) Exit Criteria

Milestone A (Approval to Begin Program)

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

Milestone B (Approval to Enter Development)

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

Interim Event (corresponding to historical Preliminary Design Review)

- Preliminary Manufacturing and Quality Plans developed

Manufacturing Development Guide

- Initial Contractor PCM developed and under formal configuration control.
- Rationale provided to correlate initial cost estimates and cost risk mitigation effort to achieve an acceptable production cost estimate.
- Design trade process implemented for evaluating alternative materials and production processes and identifying key product characteristics and related key production processes, including the results of key supplier efforts.
- Manufacturing Capability Assessment or Manufacturing Readiness Assessment conducted
- Risk abatement milestones included in IMP.
- Process capability database includes all key processes.
- Supplier capacity risks identified and included in risk management planning.
- Key suppliers identified and selected and subcontracts negotiated.
- Key supplier concurrence with requirements allocation and flow-down accomplished.
- Key supplier identification of preliminary key product characteristics.
- Associate Contractor Agreements finalized with GFP suppliers.
- Supplier Manufacturing Capability Assessment (MCA) or Manufacturing Readiness Assessment performed and results presented for suppliers not previously evaluated.
- Identification of preliminary key product characteristics complete.
- Identification of preliminary key processes complete.
- Flow down of key process requirements complete.
- Plan developed to verify and validate new processes.

Interim Event (corresponding to historical Critical Design Review)

- Manufacturing and Quality Plans updated
- Process capabilities are adequate for product requirements for prime and subcontractors.
- Production cost estimates demonstrate cost objective is achievable
- Cost mitigation actions are being completed
- Producibility studies have been completed and recommendations are incorporated in the product design
- Simulations have been conducted to verify production plans, taking into account facility manpower, and process limitations
- Selection of production processes complete, including comparison of required process capabilities to documented capabilities.

Manufacturing Development Guide

- Manufacturing Capability Assessment or Manufacturing Readiness Assessment updated.
- Test article build plan complete.
- Key supplier detailed designs complete.
- Key supplier identification of key process parameters complete.
- Final key product characteristics determined.
- Final key production process parameters determined.
- VR Program plan is in place
- Initial process control plans have been developed
- Process capability studies are being conducted with results fed back to product design
- VR metric developed
- All ST/STE scheduled for verification and validation before LRIP.
- Plan in place for conducting First Article Inspections and process proofing. IMP identifies all open tests.

Interim Event (corresponding to historical System Verification Review)

- Production Cost Model updated and demonstrates low risk in achieving cost objective.
- Simulations verify and validate assembly processes prior to LRIP.
- Risk reduction tasks for manufacturing processes are completed successfully.
- Process capability verification complete
- Key supplier designs documented and baselined
- Final process control plans for supplier processes completed.
- Key supplier risk assessment completed.
- Key supplier events/activities included in IMP.
- Preliminary Build-to documentation complete including identification of key characteristics.
- All process control plans for critical processes have been developed and are in place

Milestone C (Approval to Enter Production)

- Production cost estimates demonstrate production cost requirements are achievable with acceptable risk

Manufacturing Development Guide

- Final Build-to documentation complete, including identification of key characteristics and control plans for key characteristics.
- Process capability data is being collected on processes affecting KCs and is available to the IPTs
- Process stability and capability have been determined for key processes. For those with insufficient data, estimates of stability and capability have been made.
- Process improvements have been initiated for processes with unacceptable variation
- Metrics are used to measure the progress of the VR program
- All First Article Inspections and Process Proofing activities have been completed. Plans are in place to correct findings.
- Continuous collection and periodic review of production and quality data occurs to identify areas for improvement.
- Key supplier risk assessment and abatement planning complete and being implemented
- Verification/validation of key supplier process control and VR processes evaluated routinely
- Implementation initiatives focused on elimination of non-value-added activity and/or optimization of production cycle time (such as Lean Aerospace Initiative).

Appendix V: Suggested Inputs for Instructions to Offerors and Evaluation Criteria (Sections L and M)

Instructions to Offerors Guidance (Section L)

To be included in Factor 3: Mission Capability; Subfactor 2: Systems Engineering

These Section L and M provisions should be tailored to match the needs of the program, depending upon:

- a. The phase of the program.
- b. The amount of planned product and process development.
- c. Anticipated production quantities.
- d. Overall manufacturing risks.
- e. Factors that will yield key discriminators and meaningful comparisons in support of a source selection decision.

SUBFACTOR 1: Engineering for Affordability and Producibility. The offeror shall describe their:

- a. Processes for allocating cost requirements to lower level IPTs and suppliers.
- b. Formal programs, tools, and techniques to be used in engineering for affordability.
- c. Methods for including cost and producibility considerations in design trade studies.
- d. Flow-down of affordability requirements, tools, techniques, and practices to appropriate suppliers.
- e. Anticipated cost drivers for this program and plans for controlling those costs.

SUBFACTOR 2: Quality Systems. The offeror shall describe how their quality system assures product quality, achieves stable, capable processes, prevents defects, and employs effective methods for conducting root cause analyses and implementation of corrective actions.

Manufacturing Development Guide

SUBFACTOR 3: Manufacturing Risk Management. The offeror shall describe how manufacturing risks will be identified and managed and how supplier risks will be considered. The offeror shall describe potential risks to the program and plans for mitigating those risks.

SUBFACTOR 4: Supplier Management. The offeror shall describe their:

- a. Approach to selecting and managing key suppliers.
- b. Processes for evaluating suppliers' cost, schedule, and quality performance.
- c. Processes for integration of key supplier activities into the overall program plan to assure that supplier activities support the overall program performance.
- d. Specific potential supplier risks to the program and plans for mitigating those risks.

SUBFACTOR 5: Manufacturing Plan. The offeror shall describe:

- a. The major assembly sequence chart and anticipated manufacturing process flow.
- b. Manufacturing build schedule, including drawing release, production planning development and completion, tooling design, build, and proofing, supplier deliveries, and fabrication, assembly, and delivery schedules.
- c. Facility requirements and facility layouts.
- d. Required capacity for planned delivery rates and offeror's ability to provide the needed manpower, facility, and equipment.

Evaluation Criteria Guidance (Section M)

SUBFACTOR 1: Engineering for Affordability and Producibility. This subfactor evaluates the offeror's plans to incorporate affordability and producibility considerations into the product and process design. This subfactor is met when the offeror's proposal:

- a. Describes processes that allocate cost requirements to lower level IPTs and suppliers.
- b. Details specific programs, tools, or techniques to effectively incorporate affordability goals or requirements into the design process.
- c. Describes how cost and producibility factors are considered in design trade studies.
- d. Describes specific affordability requirements that will be flowed to suppliers.

Manufacturing Development Guide

e. Lists specific program cost drivers, demonstrating an understanding of program requirements, and proposes sound methods to control those cost drivers.

SUBFACTOR 2: Quality Systems. This subfactor evaluates the offeror's planned quality assurance system. This subfactor is met when the offeror's proposal describes sound policies and practices that will:

- a. Assure product quality.
- b. Achieve stable, capable processes.
- c. Prevent defects.
- d. Result in effective root cause analyses and corrective actions.

SUBFACTOR 3: Manufacturing Risk Management. This subfactor evaluates the offeror's risk management efforts as they relate to manufacturing issues. This subfactor is met when the offeror's proposal:

- a. Describes how manufacturing risks will be identified and managed, including supplier risks.
- b. Lists specific program manufacturing risks, demonstrating an understanding of program requirements, and proposes sound methods to mitigate those risks.

SUBFACTOR 4: Supplier Management. This subfactor evaluates the offeror's proposed supplier management program. This subfactor is met when the offeror's proposal:

- a. Describes how key suppliers are selected and managed.
- b. Describes effective processes for evaluating suppliers' cost, schedule, and quality performance.
- c. Describes how supplier activities will be integrated into the overall program plan.
- d. Lists specific supplier risks and sound approaches for mitigating those risks.

SUBFACTOR 5: Manufacturing Plan. This subfactor evaluates the proposed methods, schedules, and resources for producing the required products. This subfactor is met when the offeror's proposal:

- a. Describes the major assembly sequence and sound manufacturing process flows.

Manufacturing Development Guide

- b. Includes an integrated, achievable schedule incorporating design, tooling, supplier, fabrication, assembly, and delivery milestones.
- c. Describes realistic facility requirements and sound facility layouts.
- d. Describes how the offeror will provide sufficient resources to meet anticipated delivery rates.

Manufacturing Development Guide

Appendix VI: Reference Material

Disclaimer: These references are provided to add support and additional background information. The Air Force does not necessarily support or endorse all of the material contained in these sources.

Engineering for Affordability & Producibility

- *Product Design for Manufacture & Assembly*, by Boothroyd, Dewhurst, & Knight

Quality Systems

- *AS 9100 Aerospace Quality Systems*

Key characteristics & Processes

- *SAE AS9103, "Variation Management of Key Characteristics"*
- *Joint Aeronautical Commander's Group, "Management of Critical Safety Items"*

Variability Reduction

- *SAE AS9103, "Variation Management of Key Characteristics"*
- *"Six Sigma Producibility Analysis and Process Characterization"* by Mikel J.

Harry and J. Ronald Lawson

- *"Six Sigma: The breakthrough management strategy revolutionizing the world's top corporations"* by Mikel J. Harry and Richard Schroeder
- *"Reducing Process Variation"* by Davis Bothe

Virtual Manufacturing

- *"Simulation Modeling & Analysis"* by Averill M. Law
- *"The Virtual Engineer: 21st Century Product Development"* by Howard C. Crabb
- *"The Technology Machine: How Manufacturing Will Work in 2020"* by Patricia E. Moody

Mfg Process Control & Continuous Improvement

- *"Reducing Process Variation"* by Davis Bothe

Factory Efficiency

- *SAE J4000, "Identification & Measurement of Best Practice in Implementation of Lean Operation"*
- *"Running Today's Factory: A Proven Strategy for Lean Manufacturing"* by Charles Standard and Dale Davis