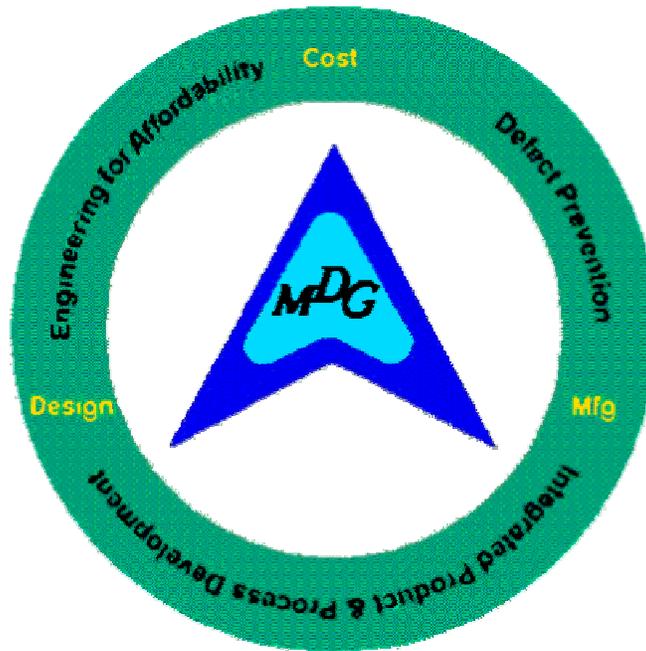




*Manufacturing
Development Guide
January 2004*



Unrestricted copying of this document is authorized. Requests for updates, copies of this document or comments may be sent to:

David Karr
ASC/ENSM
2530 Loop Road West
Wright-Patterson Air Force Base, OH 45433-7101
Phone: (937) 255-9581

Table of Contents

<i>Executive Summary</i>	6
Chapter 1: INTRODUCTION	10
1.1 The Purpose of the Manufacturing Development Guide	10
1.2 A Statement of the Problem	10
1.3 Root Cause.....	12
1.4 MDG Success Criteria	13
1.5 Manufacturing Development Guide Technical Content	14
1.6 The Relationships among Practices.....	15
1.7 Benefits.....	15
1.8 Relationship to Operational Safety, Suitability & Effectiveness (OSS&E).....	16
Chapter 2: ACQUISITION STRATEGY	17
2.1 Financial Considerations.....	17
Funding Requirements for Development and Production.....	17
MDG Cost Estimating Considerations.....	18
2.2 Contracting Considerations	20
Chapter 3: MANUFACTURING ENGINEERING'S ROLE IN IPPD	21
3.1 Introduction.....	21
3.2 Rationale.....	22
3.3 Guidance.....	23
3.4 Lessons Learned.....	24
Chapter 4: ENGINEERING FOR AFFORDABILITY AND PRODUCIBILITY	25
4.1 Introduction.....	25
4.2 Rationale.....	25
4.3 Guidance.....	26
4.4 Lessons Learned.....	28
Chapter 5: QUALITY SYSTEMS	31
5.1 Introduction.....	31
5.2 Rationale.....	31
5.3 Guidance.....	31

5.4 Lessons Learned.....	33
Chapter 6: BEST PRACTICES GUIDELINES.....	34
6.1 Introduction.....	34
6.2 Manufacturing Capability Assessment and Risk Management	35
6.2.1 Introduction	35
6.2.2 Manufacturing Capability Assessment and Risk Management Rationale	36
6.2.3 Manufacturing Capability Assessment and Risk Management Guidance	36
6.2.4 Manufacturing Capability Assessment and Risk Management: Lessons Learned	37
6.3 Production Cost Modeling	38
6.3.1 Introduction	38
6.3.2 Production Cost Modeling Rationale	38
6.3.3 Production Cost Modeling Guidance	39
6.3.4 Production Cost Modeling Lessons Learned	40
6.4 Key Suppliers	41
6.4.1 Introduction	41
6.4.2 Key Suppliers Rationale.....	42
6.4.3 Key Suppliers Guidance.....	42
6.4.4 Key Suppliers Lessons Learned	43
6.5 Key Characteristics and Processes	43
6.5.1 Introduction	43
6.5.2 Key Characteristics and Processes Rationale.....	44
6.5.3 Key Characteristics and Processes Guidance.....	44
6.5.4 Key Characteristics and Processes Lessons Learned	46
6.6 Variability Reduction	46
6.6.1 Introduction	46
6.6.2 Variability Reduction Rationale.....	47

6.6.3 Variability Reduction Guidance.....	48
6.6.4 Variability Reduction Lessons Learned.....	52
6.7 Virtual Manufacturing.....	53
6.7.1 Introduction.....	53
6.7.2 Virtual Manufacturing Rationale.....	55
6.7.3 Virtual Manufacturing Guidance.....	56
6.7.4 Virtual Manufacturing Lessons Learned.....	56
6.8 Design Trade Studies.....	57
6.8.1 Introduction.....	57
6.8.2 Design Trade Studies Rationale.....	57
6.8.3 Design Trade Studies Guidance.....	58
6.8.4 Design Trade Studies Lessons Learned.....	61
6.8.5 Contract Data Requirements List (CDRL) Guidance.....	61
6.9 Product and Process Validation.....	62
6.9.1 Introduction.....	62
6.9.2 Product and Process Validation Rationale.....	62
6.9.3 Product and Process Validation Guidance.....	62
6.9.4 Product and Process Validation Lessons Learned.....	63
6.10 Manufacturing Process Control and Continuous Improvement.....	64
6.10.1 Introduction.....	64
6.10.2 Manufacturing Process Control and Continuous Improvement Rationale.....	64
6.10.3 Manufacturing Process Control and Continuous Improvement Guidance.....	65
6.10.4 Manufacturing Process Control and Continuous Improvement Lessons Learned.....	65
6.11 Factory Efficiency.....	66
6.11.1 Introduction.....	66
6.11.2 Factory Efficiency Rationale.....	66

6.11.3 Factory Efficiency Guidance.....	66
6.11.4 Factory Efficiency Lessons Learned	68
6.11.5 Factory Efficiency Recommended RFP/Proposal Content Contract Data Requirements List (CDRL) Guidance.....	69
6.12 Technology Obsolescence & Diminishing Manufacturing Sources (DMS)	69
6.12.1 Introduction	69
6.12.2 Technology Obsolescence & Diminishing Manufacturing Sources Rationale	71
6.12.3 Technology Obsolescence & Diminishing Manufacturing Sources Guidance	72
6.12.4 Product and Process Validation Lessons Learned.....	73
<i>Appendix I: MDG Acronyms.....</i>	<i>i</i>
<i>Appendix II: Consolidated List of RFP Inputs.....</i>	<i>iii</i>
<i>Integrated Master Plan (IMP) Exit Criteria.....</i>	<i>viii</i>
Milestone I (Approval to Begin Program).....	viii
Milestone II (Approval to Enter EMD)	ix
Interim Event (corresponding to historical Preliminary Design Review)	x
Interim Event (corresponding to historical Critical Design Review).....	xii
Interim Event (corresponding to historical System Verification Review).....	xiii
Milestone III (Approval to Enter Production)	xiv
Production Phase IMP Roll-ups	xv
Instructions to Offerors Guidance (Section L).....	xv
Evaluation Criteria Guidance (Section M).....	xx
<i>Appendix III: Reference Material.....</i>	<i>xxiv</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 is fully compatible with the Defense Department's "Acquisition Reform," "Transformation," and "Lean Aerospace" initiatives. This document describes fundamental best practices and, therefore, most new initiatives or policy changes should not affect the practices described here.

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 11 MDG best practices and their application throughout the acquisition life cycle. An appendix contains suggested wording for Statements of Objectives, Contractor SOWs, 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 Manufacturing Development Guide 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. For each

practice discussed, the MDG 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. In addition, the PCM will be a critical tool for implementing Cost as an Independent Variable (CAIV). 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. They should be selected based on a proven ability 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. 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.

9. 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.

10. 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.

11. 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 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 Systems Program Office (SPO) personnel at the Air Force Materiel Command's (AFMC) Aeronautical Systems Center (ASC) 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; and (3) ineffective risk assessment, mitigation, and monitoring activities supporting critical process development.

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 at all supplier levels.
- 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.

Manufacturing Development Guide

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 Manufacturing Development Guide identifies 10 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 11 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.

Appendix II, Recommended RFP and contract language contains sample language for Contractor Statements of Work (CSOWs), 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. Finally, the MDG recommends that an Average Unit Production Price (AUPP) requirement be included in the System Specification to emphasize affordability and the concept of Cost As an Independent Variable (CAIV).

Appendix III, 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 EMD 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.

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 are 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.

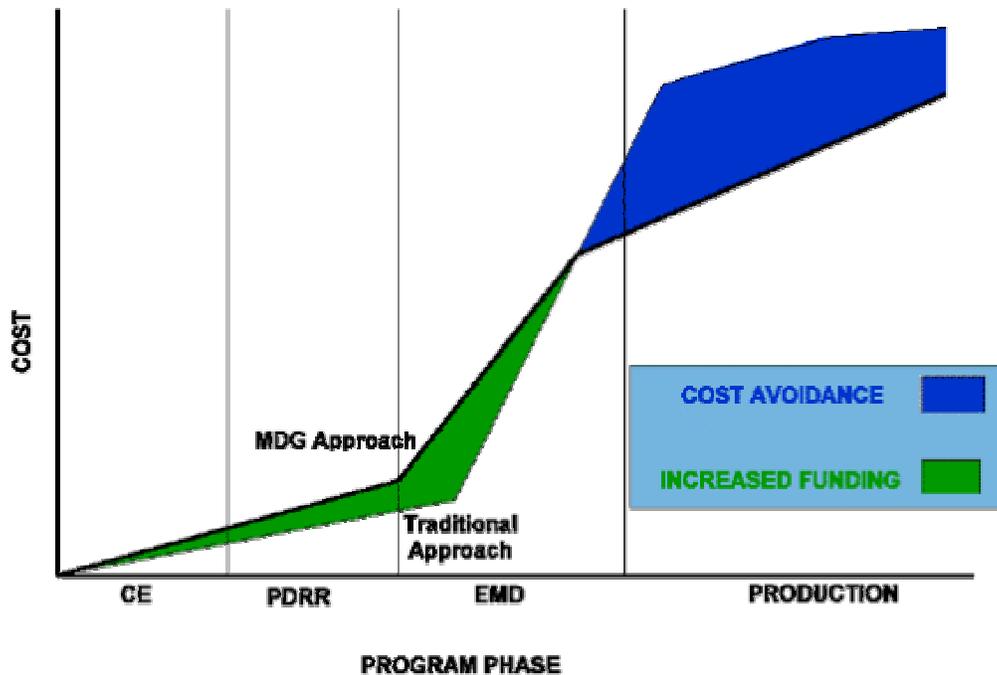


Figure 2-1. A Comparison of MDG and Traditional Program Funding Profiles

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

Manufacturing Development Guide

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 engineering and manufacturing development phase (EMD), with changes being made from late in EMD 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 should create lower first unit production costs and improve efficiency by moving both prime contractor and subcontractor labor to a flatter portion of the cost curve.

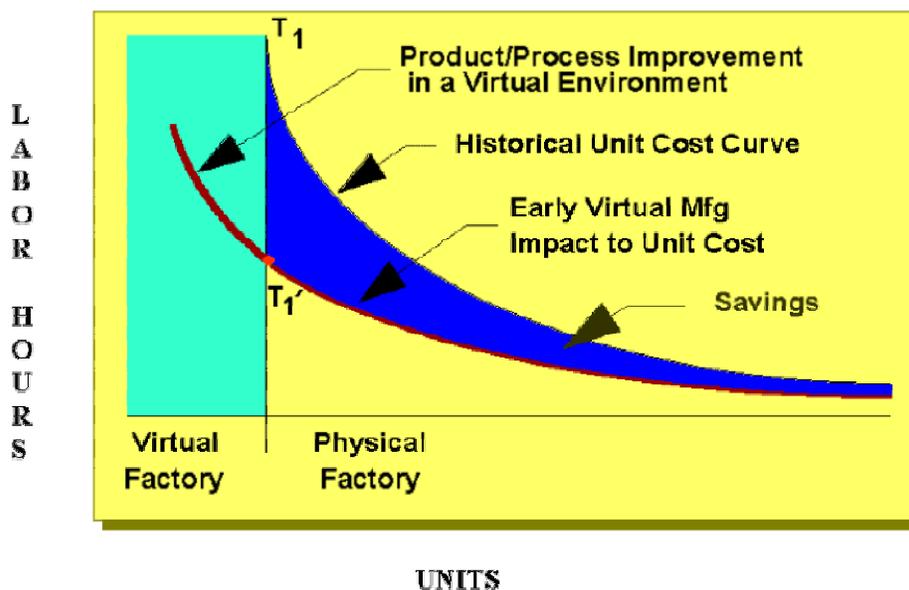


Figure 2-2 Product/Process Improvement in a Virtual Factory Environment

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.

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)
- 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 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 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 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 (variability reduction, VR). 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 SPO 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.

3.4 Lessons Learned

The use of IPTs has demonstrated clear benefits in reducing product design time and cost. With representatives of all stakeholder functions involved from the beginning, the team integrates the design, manufacturing, quality, and key personnel from other disciplines into a focused, results-driven unit. The inclusion of customer and supplier personnel has further increased the effectiveness of IPTs in achieving high quality product definition. Most of the DoD's more recent product design efforts have employed IPTs and reported both cost and schedule benefits. Effective IPPD has reduced the number of engineering changes, resulting in shorter design development times and reduced labor since rework of the design is diminished. Reductions in tooling design and fabrication costs as well as rework in early production are additional benefits of the IPPD process.

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.

The Manufacturing Engineer leads the problem solving process, addressing both the processes and the design to achieve a balanced and affordable product. Scrap/rework levels and cost have been significantly reduced, and schedule performance improved, by contractors applying these practices.

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.

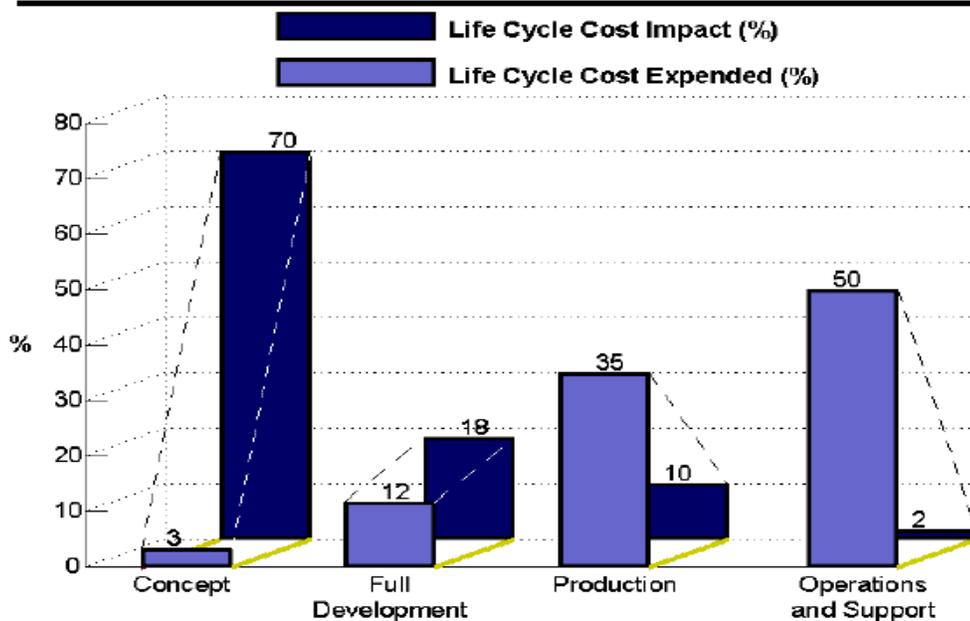
In general, there are four approaches to engineering for affordability which can be combined as necessary to create the best tool for the circumstance: (1) affordability as a foundational responsibility for all engineers; (2) a dedicated producibility program; (3) a distinct affordability program; and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

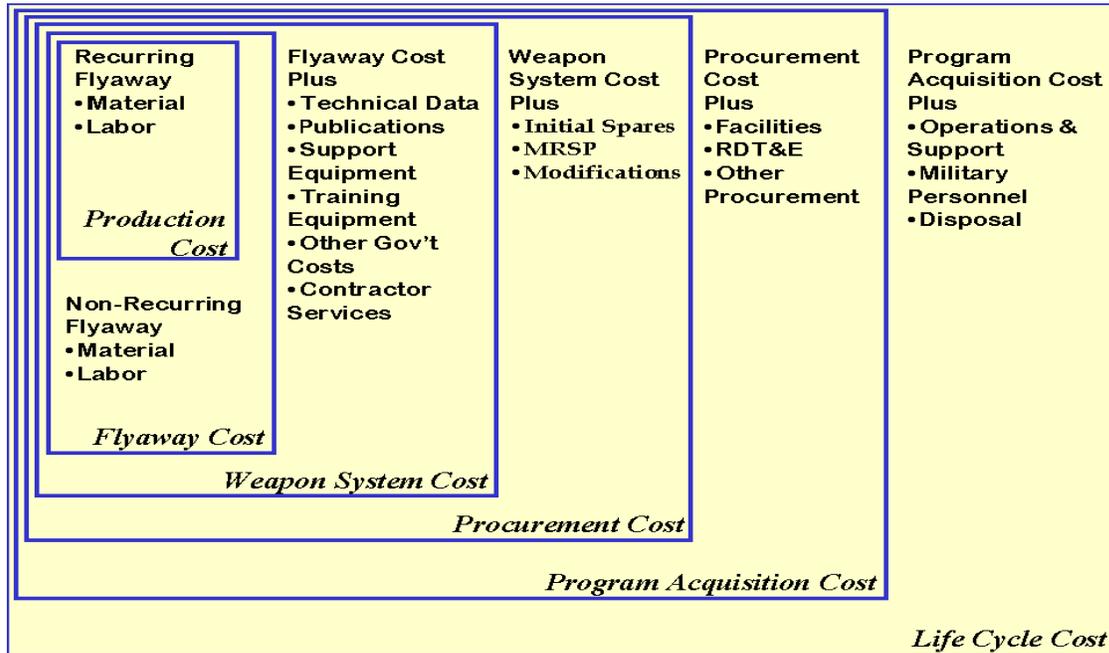


Figure 4-2. Life Cycle Costs - Total Ownership Costs

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 Effort: Three tools/practices contribute significantly to improving producibility when integrated into the Systems Engineering process: Design for Manufacturing & Assembly, Manufacturing Capability Assessments, and Determinant Assembly.

Design for Manufacturing & Assembly (DFMA) is an affordability tool developed by Boothroyd Dewhurst, Inc. and is widely accepted for facilitating cost reduction activities. It includes design guidelines for improving the ease of assembly, such as reduced parts count, minimizing types of fasteners, and multi-use parts. Monolithic parts (larger parts

which contain smaller parts such as brackets and stiffeners that are forged, cast, or machined integrally into the basic part) can also reduce assembly time. DFMA also includes a methodology to evaluate proposed designs to determine how well they incorporate the DFMA principles and to provide a measurable assessment of the design's producibility.

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 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.

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

DFMA has been very successful where it has been implemented. Figure 4-3 presents a summary of the benefits obtained from the application of Design for Manufacturing and Design for Assembly processes in 66 published case studies. (Source: "A Decade of DFMA Research," G. Boothroyd, Proceedings of the 1994 International Forum of Design for Manufacture and Assembly, from the June 13-14, 1994 edition.)

Category	Number of Studies	Average Reduction (%)
Part Count	55	57
Separate Fasteners	12	72
Assembly Time	37	63
Assembly Cost	16	45
Product Cost	15	51
Product Development / Time to Market	4	50
Manufacturing Cycle Time	6	58

Figure 4-3. Design for Manufacturing and Assembly Results.

Conversely, previous experience with DTC 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. DTC programs must also rely on a current Production Cost Model that is continually updated to reflect programmatic changes.

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/A-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

Manufacturing Development Guide

will decrease primarily due to the reduced number of units that will experience the benefits. The F/A-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.

5.3 Guidance

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 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.

Manufacturing Development Guide

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

- Management commitment to quality and a customer focus.
- 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.

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.

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 III 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.

Chapter 6: BEST PRACTICES GUIDELINES

6.1 Introduction

The SPO 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 (ME) function 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 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	
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 engineer 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. This model (with associated software) is available on the ASC/EN web page.

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.

Production planning was previously the focus of a series of incremental Production Readiness Reviews (PRRs), typically performed to support the decision to go into Low Rate Initial Production and, later, Full Rate Production. The MDG supplements the PRR

with a more comprehensive manufacturing review function that begins at the start of development and continuously assesses and manages risk at both the prime contractor and supplier level. Manufacturing risk reviews and reporting should be a formal part of the Technical Interchange Meetings (TIMs) or equivalent system and subsystem reviews, leading up to design and production readiness reviews.

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)

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 in the implementation of Cost as an Independent Variable (CAIV). The ability to balance cost, performance and schedule is an integral part of CAIV and the Integrated Product and Process Development (IPPD) concept, but 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, 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.

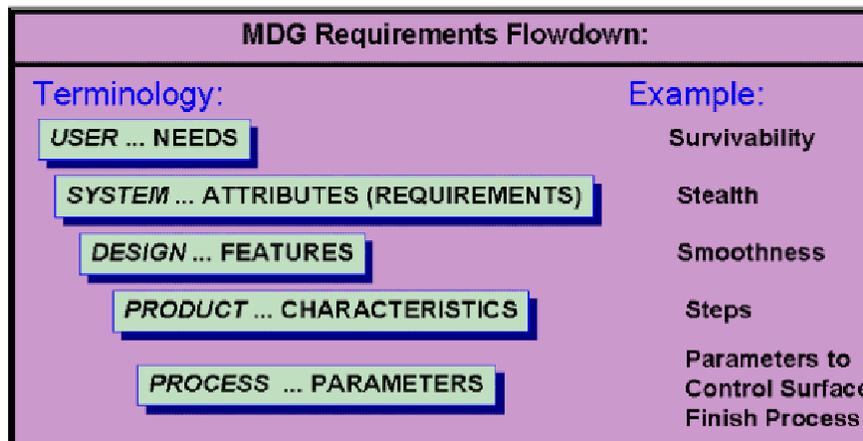


Figure 6-1. Requirements Flow-down Terminology

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.

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.

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.

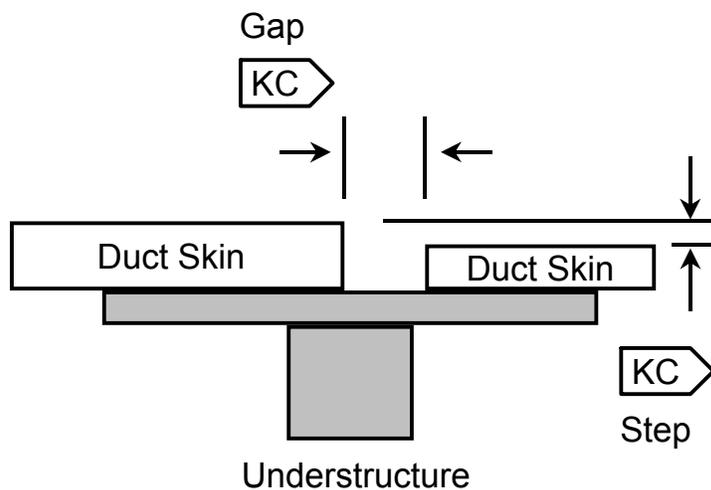


Figure 6-2. KC Flags on Drawings

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.

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.

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.

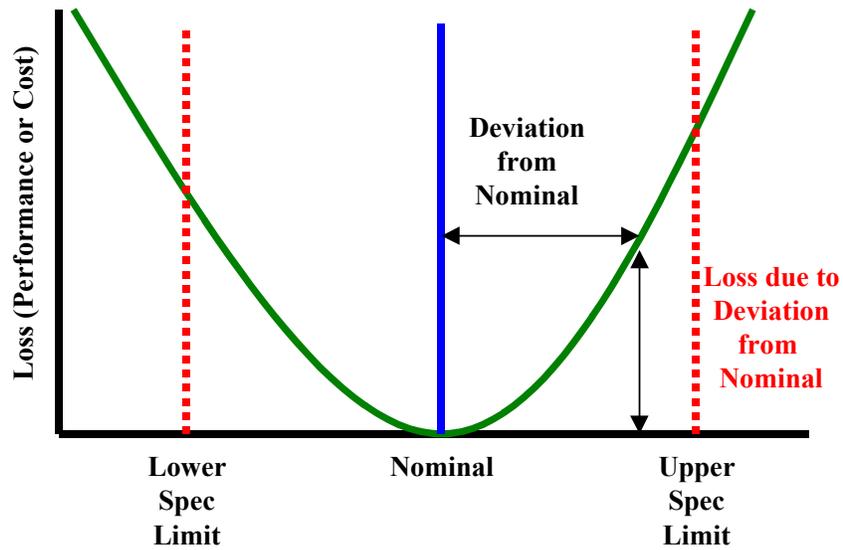


Figure 6-3. The Taguchi Loss Function

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.

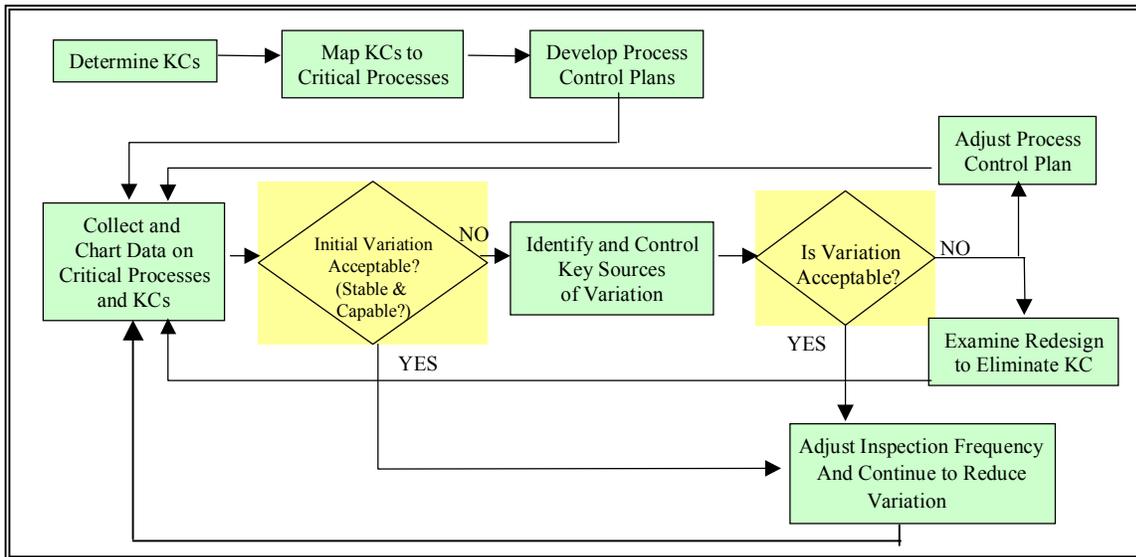


Figure 6-4. VR General Approach

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 can not 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:

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

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.

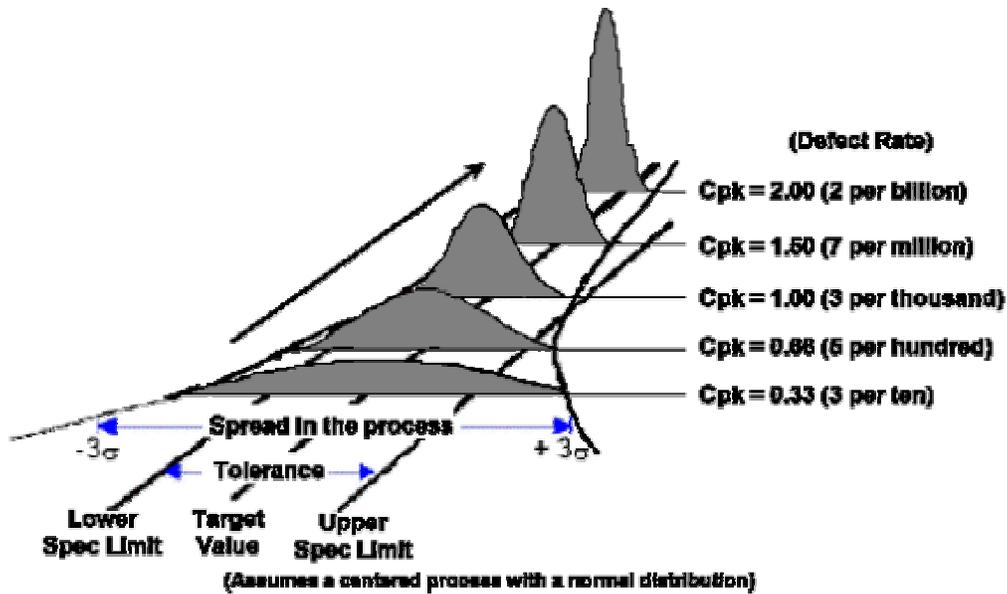


Figure 6-5. Capability Index

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.

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 are 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 utilize 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 and supportability 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, including producibility and supportability, 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. The potential for trading cost versus performance makes the benefits of Commercial-off-the-Shelf (COTS) products more attractive to the design team.

6.8.3 Design Trade Studies Guidance

Careful consideration of producibility and supportability 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.

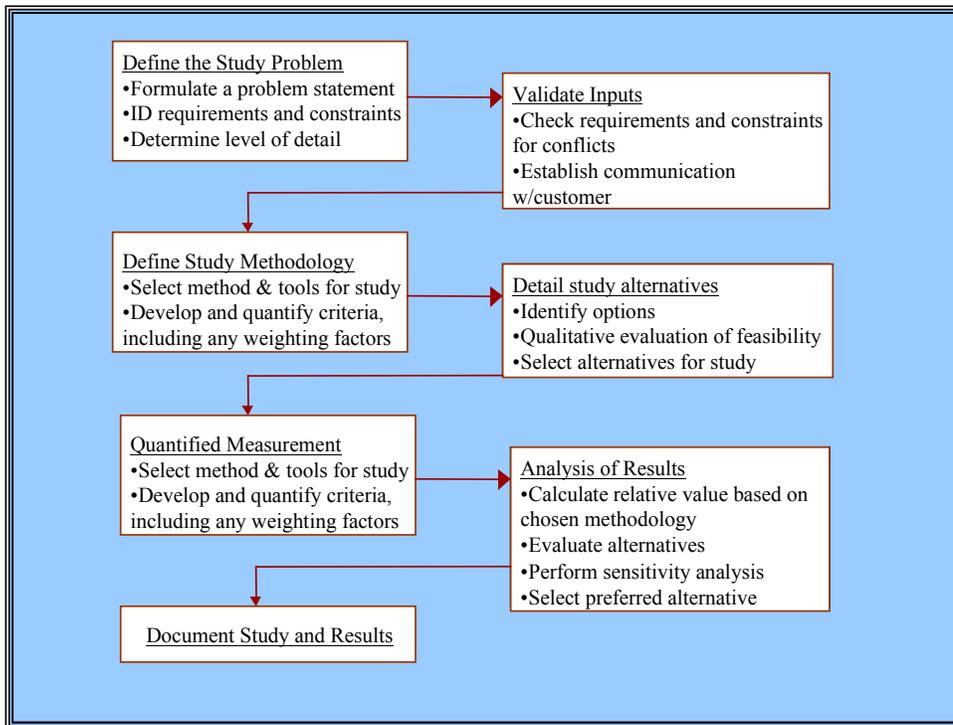


Figure 6-6 Trade Study Process

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.

One common and widely accepted method of evaluation of trade studies is described here as an example. Further detail, and descriptions of other techniques, 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.

6.8.3.1 Utility Curve Methodology

The Utility Curve Methodology is a technique commonly used by DoD and industry to analyze trade alternatives. It is also used in a modified form for proposal evaluation.

Manufacturing Development Guide

A Utility Curve is established for each performance factor, showing the relative value for each factor throughout its range (see figure 6-7 below).

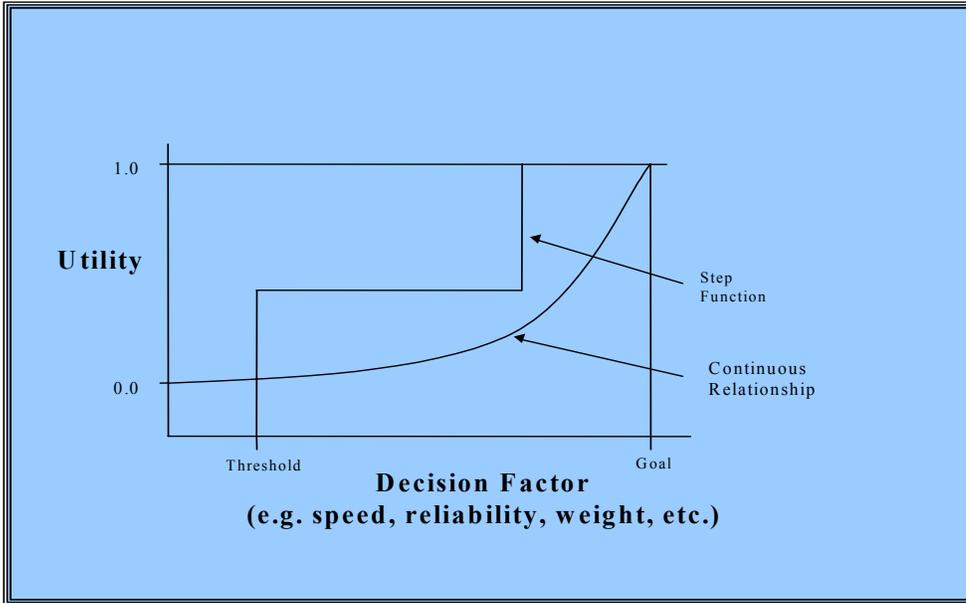


Figure 6-7 Sample Utility Curve

Alternatives	Range (Wt=2.0)		Speed (Wt=1.0)		Payload(Wt=2.5)		Weighted Total
	U	W	U	W	U	W	
System Option 1	.8	1.6	.7	.7	.6	1.5	3.8
System Option 2	.7	1.4	.9	.9	.4	1.0	3.3
System Option 3	.6	1.2	.7	.7	.8	2.0	3.9★
System Option 4	.5	1.0	.5	.5	.9	2.25	3.75

Key: U = Utility Value W = Weighted Value ★ - Apparent winner

Figure 6-8 Sample Decision Matrix

By normalizing all factors on a zero-to-one utility scale, it is easier to make a comparison. The relative value of the performance factors is reflected in a “Decision Matrix” where each performance factor is given a weighting factor. Combining the weight factor and the performance factor utility score gives the relative “value” for each factor under each alternative. Adding the values for an alternative’s factors will give a total performance score, which is comparable to the scores of all other alternatives. The winning alternative is the one with the highest total score (see figure 6-8 for a sample decision matrix).

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 and supportability 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 and supportability 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.

6.8.5 Contract Data Requirements List (CDRL) Guidance

For on-going single source production programs:

- Information copies of specifications and product descriptions through the Data Accession List (DAL), with delivery upon request.

For multiple source production or delayed production programs:

Option 1: Contractor maintained library

- Information copies of specifications through the DAL, with delivery upon request.

Option 2: Government maintained library

- Product Development Definitions upon completion.
- Product Design Definitions upon completion.
- Product Fabrication Definitions at Milestone III.
- Technical Data Package and Build-to Package at Milestone III.

6.9 Product and Process Validation

6.9.1 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 verifying 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.

6.9.2 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.

6.9.3 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 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 rapid 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.

6.9.4 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.

6.10 Manufacturing Process Control and Continuous Improvement

6.10.1 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.

6.10.2 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.

6.10.3 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.

6.10.4 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.

6.11 Factory Efficiency

6.11.1 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.

6.11.2 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

6.11.3 Factory Efficiency Guidance

Figure 6-9 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.

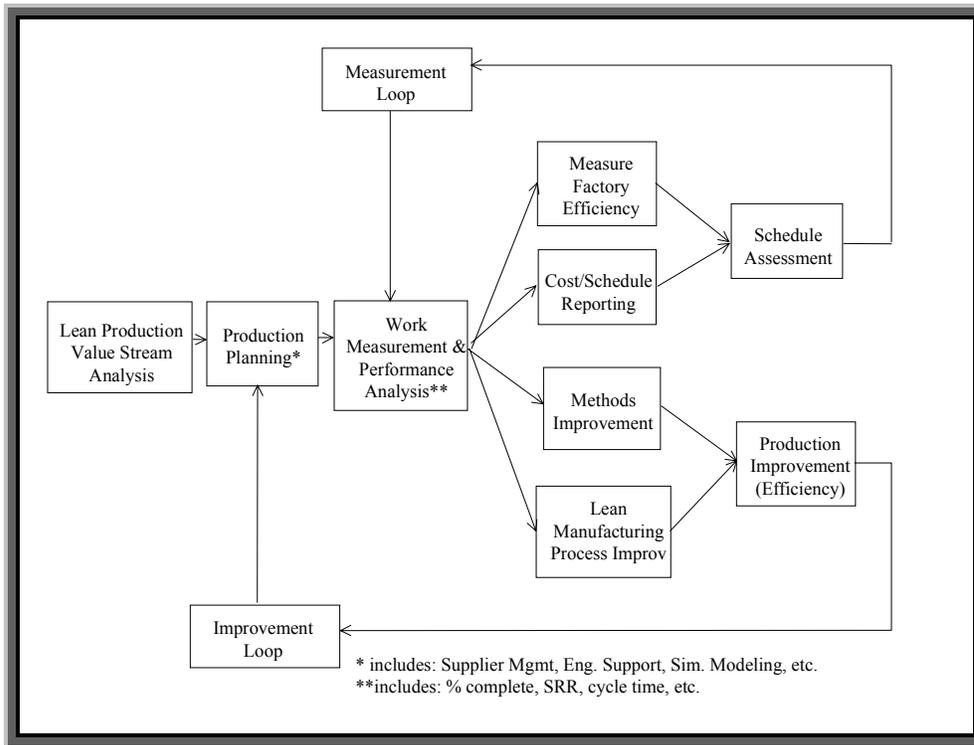


Figure 6-9. How the Factory Efficiency Practice Area Integrates with Other Practices

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 6-10, 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.

Manufacturing Development Guide

- 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.
- Cycle times: total duration of a task.

6.11.4 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 many programs.

6.11.5 Factory Efficiency Recommended RFP/Proposal Content Contract Data Requirements List (CDRL) Guidance

With the Acquisition Reform emphasis on eliminating all but the most essential data requirements, those responsible for Manufacturing and Quality Assurance find themselves in a position where they are required to aggressively defend the requirement for factory efficiency data. Winning the argument for receiving this data is critical to program success on everything but a straightforward COTS procurement. Program management must understand that eliminating this data requirement means blinding themselves 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.

CDRLs will vary depending on the type of contract used, the degree of new development effort, and the phase of the acquisition lifecycle. Minimizing the number of actual CDRLs is highly desirable, and it may be possible to eliminate delivery of paper entirely through agreements on shared access to contractor's databases (a common practice within IPTs).

- Summary Production Schedule
- Labor Performance Data (actual hours vs. work measurement standards)
- Intermediate Detailed Departmental Schedule and Performance Charts
- Line of Balance Charts
- Scrap, Rework and Repair metrics
- Supplier Factory Metrics (when available)

6.12 Technology Obsolescence & Diminishing Manufacturing Sources (DMS)

6.12.1 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 6.10). 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.

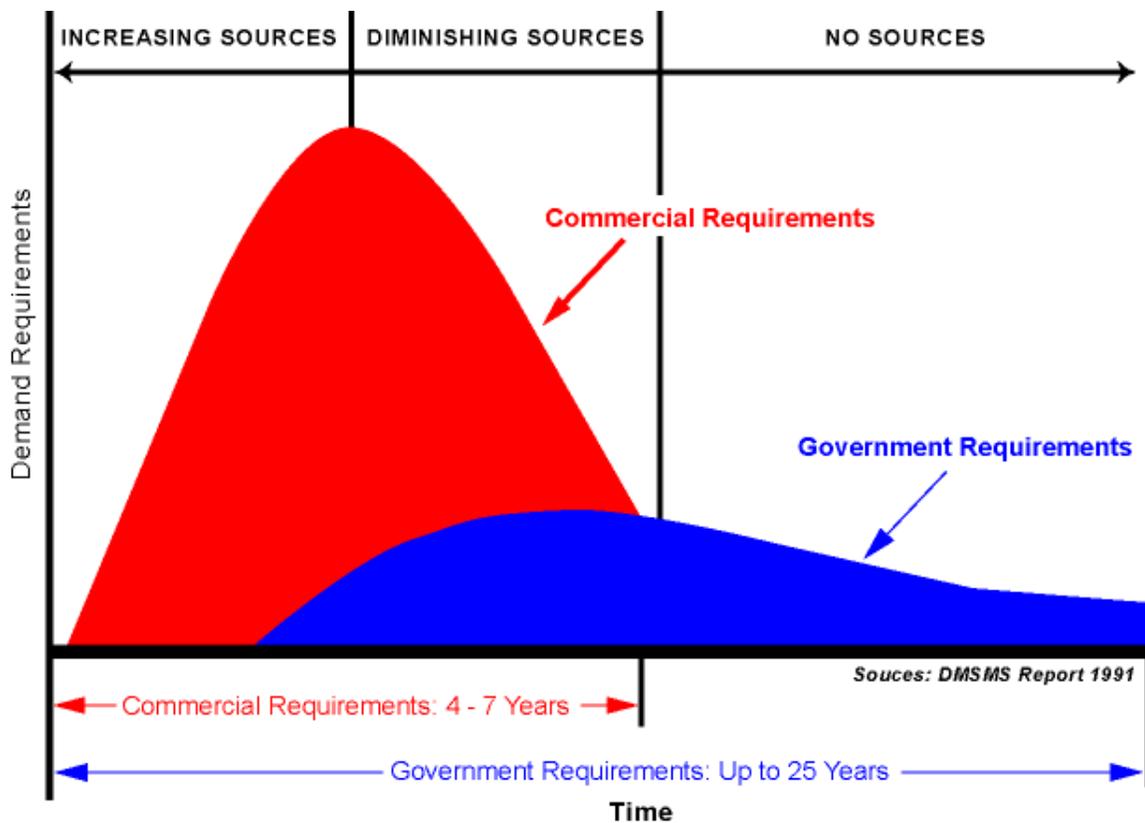


Figure 6.10

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.

6.12.2 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 6.11). So it falls to the system developer to make the best use of the technology that is available, while it is available.

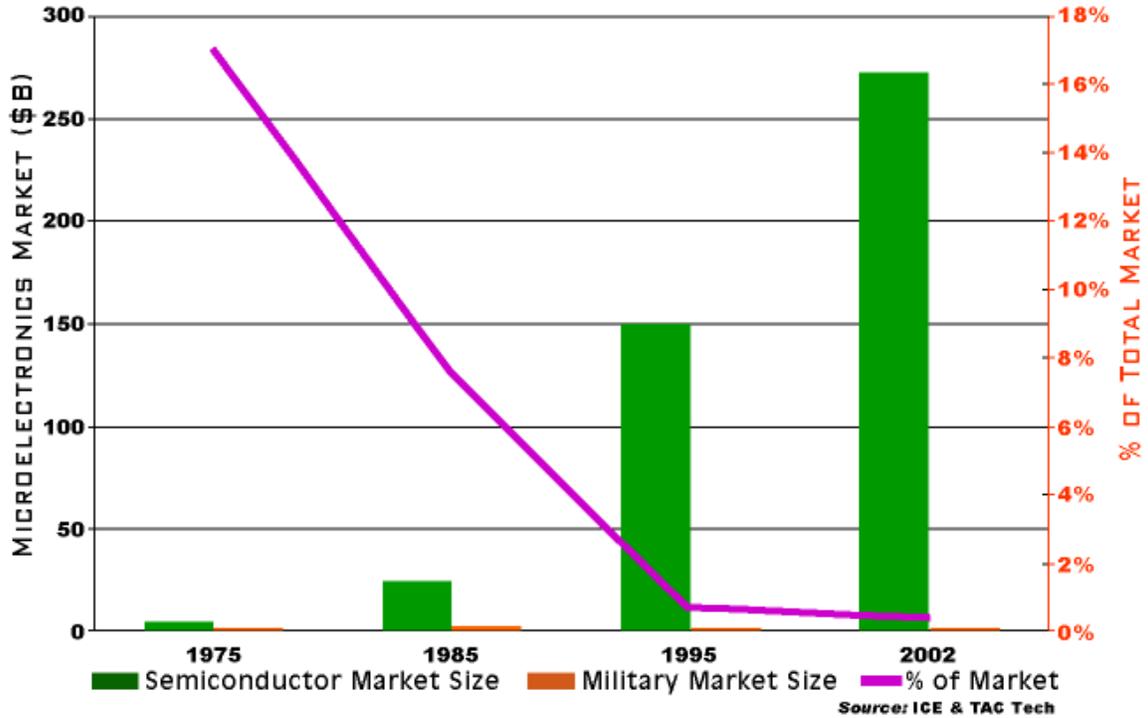


Figure 6.11

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.

6.12.3 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.”

6.12.4 Product and Process Validation 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
PBBD	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
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
SPO	System Program Office
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

Appendix II: Consolidated List of 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. Appropriate practices for implementation may include production cost modeling; identification of key characteristics and processes; variability reduction; electronic simulations of the manufacturing environment; Cost As an Independent Variable (CAIV); 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.

Contractor Statement of Work (CSOW)

All offerors are encouraged to address the topics below in their submitted SOWs, to the extent that they are applicable to the offeror's proposed program and the acquisition phase:

Manufacturing Engineering's role in IPPD

- Means used to involve the government customer, the required internal disciplines (including manufacturing engineering), and key subcontractors in a collaborative design process.
- Roles and responsibilities, reporting requirements, and program metrics to be followed by the IPTs.

Engineering for Affordability and Producibility

- Incorporation of cost in design/performance trade studies
- Flow down of cost targets to IPTs and key suppliers
- Offeror's formal cost risk management process
- Availability of "Engineering for Affordability" tools and training to suppliers
- The planned implementation of formal cost avoidance initiatives, programs, tools, and techniques

Quality Systems

- The contractor's SOW should address the tools and techniques that will be implemented and deployed within an overarching quality management system to prevent the production of defective products.
- The contractor's SOW should specify the means that will be used for measuring the effectiveness of all company processes that could affect quality of the product and for ensuring the continuous improvement of systems and processes.

Production Cost Modeling

- Development and maintenance of a PCM containing production cost ground rules, assumptions and data required to estimate production cost as defined in the System Specification.
- Configuration control of the model, as well as overall government and contractor roles and responsibilities for development and maintenance.
- Implementation of the PCM as an element in the systems engineering trade study process to assess production cost impacts and maintenance of an analysis of the current production cost estimate.

Manufacturing Development Guide

- Use of the production cost estimate analysis to assess the risk of achieving the System Specification cost requirement, and formulation and execution of appropriate risk abatement efforts.

Manufacturing Capability Assessment

- Risk mitigation strategies for material and process issues.
- Concurrent development of ST/STE and SE as a schedule risk reduction procedure.
- Production capability or capacity issues, industrial base sustainment plans, and foreign-sourced materials.
- IRAD and internally funded activities that apply to the reduction of risk for the program, including a brief description of the technology, expected results, and schedule.
- The metrics used for evaluation of producibility and related cost impacts in the design trade studies, including those of key suppliers.
- The plans to establish and maintain the manufacturing capability to acquire, produce, assemble, and deliver the contracted items.
- The procedures for day-to-day production planning and effective management of all tasks, facilities, and personnel required to produce the components at the prime and subcontractor facilities.

Key Suppliers

- Flow-down of key design features and key product characteristics for which suppliers are responsible.
- Identification of key suppliers, including suppliers of GFP, and integration of supplier activities into the overall program plan.
- Early supplier participation in Integrated Product Teams (IPTs).
- Implementation of Associate Contractor Agreements (ACAs).
- Integration of key supplier events/activities into the IMP.
- Identification, analysis and management of supplier risk.
- Integration of the supplier risk management plan into the program risk management plan.

Key Characteristics

- Processes for identifying key product characteristics that most influence product performance, reliability, affordability, quality, and cost as appropriate to the level of design maturity.

Manufacturing Development Guide

- Processes that balance product design requirements with manufacturing process capabilities.
- Processes for documentation of key characteristics, processes, and parameters on drawings and in appropriate process specifications.
- Flow-down of key product characteristics and key process requirements to applicable suppliers.

Variability Reduction

- Process for providing feedback to the product design engineers on process capabilities
- Determination and documentation of design margins, process capability requirements, and process control requirements for key processes and process parameters.
- Matching of product design requirements to manufacturing capabilities during the product definition process.
- Development and demonstration of methods for evaluation of process stability and capability, and for assessment of the potential for quality improvements to the product design and production processes.
- Key supplier development, implementation, and maintenance of a VR methodology encompassing all key characteristics for which they are responsible.
- Plans for data collection and analysis, evaluation and monitoring of process stability and capability, and assessment of potential benefits of process improvements.

Virtual Manufacturing

- Preliminary manufacturing planning, virtual manufacturing, and virtual prototyping tools to synthetically demonstrate and validate program approaches.
- Planned approach to virtual manufacturing to provide early links between design and manufacturing, and to facilitate performance trades.

Design Trade Studies

- A design trade study process that establishes the detailed designs of the overall weapon system and ST/STE/SE, to include selection of fabrication and assembly techniques and design parameters and tolerances that are consistent with process capabilities. This process also includes documentation of design trade study results and disposition of recommendations as the design matures.
- Identification of key product characteristics and related key production processes.
- Rationale for the functional requirements allocations and the resultant detailed designs at appropriate key events and IMP Milestones.

Manufacturing Development Guide

- Identification of design trades which fall outside program constraints of cost or schedule, but offer the potential of significant cost, schedule or performance improvements.

P&P Validation

- The appropriateness of the effort to the program considering the availability of advanced production capability demonstration resources.
- The inclusion of teammates and major suppliers in the production and process validation effort.
- The use of production and process validation to verify the build-to documentation and demonstrate the capability of the ST/STE and the processes, plans, and facilities for initial production.
- Distinctions between prototype facility processes and production facility processes.
- The scalability of any prototype facilities employed.

Process Control

- The company's process control procedures for manufacturing processes, related documentation, including configuration control of processes and ST/STE, production process flow, and production processes and methods.

Factory Efficiency

- Factory efficiency initiatives which will be used to achieve the proposed Average Unit Production Price (AUPP).
- Continuous production improvement practices to be used in the production phases.

Integrated Master Plan (IMP) Exit Criteria

Milestone I (Approval to Begin Program)

Manufacturing Engineering's Role in IPPD

- Manufacturing process design considered in product design engineering practices.
- Appropriate consideration of multi-functional IPT inputs reflected in documentation of trade-off decisions.

Engineering for Affordability and Producibility

- Preliminary production concepts identified. Preliminary cost partitioning of major assemblies accomplished.

Production Cost Modeling

- Preliminary production cost estimate documented, including ground rules, assumptions, and rationale.

Manufacturing Capability Assessment

- Materials lacking mature processes identified for manufacturing risk management purposes.
- IRAD and other programs established to reduce risk.
- Manufacturing capability database architecture defined.
- Manufacturing capacity issues identified.
- Industrial base sustainment issues identified.

Key Suppliers

- Key technology teams and strategic business alliances initiated.
- Key supplier risk assessment performed and manufacturing risk mitigation planning initiated.
- Flow-down of MDG practices to key suppliers initiated.
- Key supplier performance requirements flow-down and agreement established.

Key Characteristics

- Key Characteristics and Processes plan established.

Variability Reduction

Manufacturing Development Guide

- Preliminary VR planning accomplished

Virtual Manufacturing

- Production concepts demonstrated through simulation.
- Cost objectives and affordability initiatives confirmed through simulation.

Milestone II (Approval to Enter EMD)

Manufacturing Engineering's Role in IPPD

- Evidence exists that process considerations have influenced the product design.
- PCM demonstrates that cost objective is achievable, and associated risk reduction tasks are identified in the IMP.
- Results of producibility studies are accounted for in the product design approach.
- Customer/user and supplier members actively participated in IPT.
- Process maturation plans have been employed.

Engineering for Affordability and Producibility

- Initial cost estimates support program goals and cost risks and drivers are identified
- Results of cost vs. performance trade studies obtained
- Cost requirement flow-down refined
- Cost management/reduction systems developed and implemented

Production Cost Modeling

- Preliminary production cost model (PCM) acceptable to the government.
- Updated production cost estimates documented.

Manufacturing Capability Assessment

- Manufacturing Capability Assessment completed and risk mitigation initiatives planned
- New and/or environmentally questionable materials and processes included in program risk management planning.
- Contributions of IRAD and other independently funded programs factored into program schedule.
- Manufacturing capability database includes all technologies applicable to identified Key Characteristics.
- All risk reduction activities factored into program schedule and IMP.

Manufacturing Development Guide

- Industrial facilities and manpower requirements planning included in IMP.

Key Suppliers

- Key process characteristics and key product characteristics flow-down initiated.
- Key supplier Manufacturing Capability Assessment (MCA) performed and results presented.
- Preliminary tolerance flow-down/error budget established.
- Preliminary EMD manufacturing plans for key suppliers established.
- Preliminary electronic manufacturing simulations by key suppliers identified.
- Associate Contractor Agreements finalized with key GFP suppliers.
- Risk assessment and events/activities for key suppliers included in Integrated Master Plan.

Key Characteristics

- Preliminary key product characteristics identified.
- Preliminary key processes identified.
- Supplier flow-down of product key characteristics and key processes established.

Variability Reduction

- EMD phase VR planning completed.
- A process is in place for matching key product characteristic design requirements to process capabilities.
- Key supplier VR flow-down and training initiated.

Virtual Manufacturing

- Simulations demonstrate ability to meet producibility and affordability goals.
- Manufacturing risk areas included in simulations.
- Baseline established for EMD production activities.

Interim Event (corresponding to historical Preliminary Design Review)

Manufacturing Engineering's Role in IPPD

- Validation of process capability index is being confirmed for key processes using representative materials
- Designed experiments have been used to define a first approximation to optimum settings for process attributes.

Manufacturing Development Guide

Production Cost Modeling

- 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 Studies

- Functional allocation of System Specification requirements, including the Production Cost Requirement and overall estimate of Life Cycle Cost.
- 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

- Manufacturing Capability Assessment updated.
- Risk abatement milestones included in IMP.
- Process capability database includes all key processes.
- Plan identified to match product requirements and process capabilities.
- Supplier capacity risks identified and included in risk management planning.

Key Suppliers

- Key suppliers identified and selected and subcontracts negotiated.
- Key supplier concurrence with requirements allocation and flow-down accomplished.
- Key supplier identification of key product characteristics.
- Associate Contractor Agreements finalized with GFP suppliers.
- Supplier Manufacturing Capability Assessment (MCA) performed and results presented for suppliers not previously evaluated.

Key Characteristics

- Identification of preliminary key product characteristics complete.
- Identification of preliminary key processes complete.
- Flow down of key process requirements complete.
- Drawing system/standards and drawing release criteria defined prior to start of detailed design.

P&P Validation

- Key product components and processes evaluated from a validation standpoint.

Manufacturing Development Guide

- New processes verified and validated incrementally.
- Additional tests required for verification and validation identified.

Interim Event (corresponding to historical Critical Design Review)

Manufacturing Engineering's Role in IPPD

- Key characteristics and key processes are matched for prime and sub contractors.
- Process capabilities are adequate for product requirements for prime and subcontractors.
- Simulations have validated the assembly process.

Engineering for Affordability and Producibility

- Production cost models reflect the impact of the design solution on manufacturing costs
- 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

Production Cost Modeling

- Rationale provided to correlate cost estimates based on detailed design and cost risk abatement effort to achieve an acceptable production cost estimate.

Design Trade Studies

- Detailed design (product/ST/STE/SE) including production cost assessments and key product characteristic's design limit sensitivity to off nominal production; details to include the results of key suppliers' efforts.
- Selection of production processes, including comparison of required process capabilities to documented capabilities.

Manufacturing Capability Assessment

- Manufacturing Capability Assessment updated.
- Test article build plan complete.
- Rationale provided to demonstrate adequacy of risk abatement plans.
- Process capability demonstration plan complete and included in IMP.

Key Suppliers

- Key supplier detailed designs complete.

Manufacturing Development Guide

- Key supplier identification of key process parameters complete.
- Key supplier preliminary process specifications complete.
- Key supplier risk assessment input provided to prime contractor.

Key Characteristics

- Final key product characteristics determined.
- Final key production process parameters determined.
- Preliminary specifications for key processes developed.

Variability Reduction

- 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

P&P Validation

- All ST/STE scheduled for verification and validation before LRIP.
- IMP identifies all open tests.
- Risk management plan identifies all open risk items.

Interim Event (corresponding to historical System Verification Review)

Manufacturing Engineering's Role in IPPD

- PCM 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.

Production Cost Modeling

- Rationale provided to correlate final cost estimate based on development test results, test article build experience, (and, when applicable, Low Rate Initial Production [LRIP]) and any remaining cost risk abatement effort to be completed prior to production which results in an estimate which meets the System Specification PCR.

Design Trade Studies

- Final product/ST/STE/SE design based on results of test and evaluation, including the results of key suppliers' efforts

Manufacturing Development Guide

- Identification of potential opportunities for improving cost, schedule and/or performance beyond baseline requirements.

Manufacturing Capability Assessment

- Rationale provided to demonstrate adequacy of production risk mitigation plans.
- Process capability verification complete

Key Suppliers

- Key supplier designs documented and baselined.
- Final specifications for supplier processes completed.
- Key supplier risk assessment completed.
- Key supplier events/activities included in IMP.

Key Characteristics

- Final specifications for all key processes developed.
- Preliminary Build-to documentation complete including identification of key characteristics.

Milestone III (Approval to Enter Production)

Engineering for Affordability and Producibility

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

Key Characteristics

- Final Build-to documentation complete, including identification of key characteristics and control plans for key characteristics.

Variability Reduction

- 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

Production Phase IMP Roll-ups

Process Control

- Continuous collection and periodic review of production and quality data to identify areas for improvement.
- Manufacturing tooling and ST/STE/SE documentation are under change control.
- Processes and methods documentation are under change control.

Key Suppliers

- Key supplier concurrence with requirements allocation and flow-down.
- Key supplier risk assessment and abatement planning and implementation.
- Verification/validation of key supplier process control and VR processes.

Factory Efficiency

- Program Office insight for make vs. buy procedures.
- Implementation initiatives focused on elimination of non-value-added activity and/or optimization of production cycle time (such as Lean Aerospace Initiative).
- Continuous improvement process documentation.
- Use of cost models in economic decisions.
- Management of cost, schedule, and quality risk in the production environment.

Instructions to Offerors Guidance (Section L)

Section L should ask the offeror to describe how the objectives of this practice will be pursued, including the following:

Manufacturing Engineering's Role in IPPD

- The IPPD processes which the offeror proposes to employ.
- The proposed approach to populating multi-functional teams and ensuring participation by suppliers and/or customers.
- Plans to introduce and institutionalize the IPPD process in the offeror's organization (if the offeror has no previous IPPD experience).
- A description of the methodology used by the IPT for validating process cost and capability data to support trade decisions.

Engineering for Affordability and Producibility

- Processes for allocating cost requirements to lower level IPTs and suppliers

Manufacturing Development Guide

- Description of formal programs/tools/techniques to be used in engineering for affordability to maximize cost avoidance in manufacturing and sustainment
- Methods for including cost considerations in design trade studies
- Description of cost risk identification/mitigation processes
- Flow-down of engineering for affordability tools, techniques, and practices, along with related training, to appropriate suppliers.

Quality Systems

- How the quality system will ensure establishment of capable processes, adequate monitoring and control of critical processes and product variation, establishment of mechanisms for feedback of field product performance, implementation of an effective root cause analysis and corrective action system, and continuous process improvement.
- The offeror's quality systems should be described in the proposal to confirm that a formal, systematic approach is in place to assure product quality and prevent the generation of defective product.
- The test and evaluation program should reflect the incremental verification of objectives throughout the design cycle.
- The offeror should provide for government insight into the quality program and should flow down this insight process to appropriate suppliers.
- The proposal should reflect the offeror's plans for using commercial or industrial standards in place of government specifications, and the strategy for implementing these standards with suppliers.
- The offeror should incorporate appropriate elements of the proposed quality system into the final contract through the Integrated Management Plan.

Development Phase - Section L

Production Cost Modeling

- Established processes and procedures for developing and validating a PCM.
- Documentation and maintenance practices for control of the PCM configuration.
- The contractor's preliminary model for evaluation, if available.
- Data pertinent to prime contractor and key supplier past performance in developing and maintaining realistic PCMs or similar models.

Design Trade Studies

- Basic trade study processes to be employed, including selection criteria for principal participants and integration of planned design trade studies and results into the IMP.

Manufacturing Development Guide

- Process for System Specification requirements allocation and flow down.
- Implementation of requirements for ST/STE/SE during the design process.
- Data pertinent to the prime contractor's and key suppliers' past performance in accomplishing design trade studies, with emphasis on such studies performed under the IPT concept, including metrics which identify performance with respect to cost, schedule and product performance.

Manufacturing Capability Assessment

- How the specific manufacturing risks will be addressed, including subcontractors, and the metrics to be used and how risks will be documented and reported.
- How the risk management effort will be integrated with the overall systems engineering and IPPD processes.
- Process capability database includes all key processes.
- Industrial capacity and industrial base sustainment issues.
- Effective minimization of all hazardous materials.
- Inclusion of the environmental assessment task in the Integrated Master Plan.

Key Suppliers

- Approach to identification and selection of any new key suppliers, including key suppliers of GFP, along with criteria used to make the determination.
- Processes for evaluation of key supplier performance, including suppliers of GFP (after appropriate contractual mechanisms for relationships with key suppliers of GFP have been put in place).
- Processes for integration of key supplier activities into the overall program plan, including a description of the tasks involved and key events with their exit criteria, to assure that supplier activities support the overall program performance.
- Processes for flow-down of performance specifications and key characteristics.
- Key supplier plans for the implementation of defect prevention processes and techniques.
- Processes for integration of key supplier risk management efforts with the program risk management effort (including cost, schedule, and technical risks).

Key Characteristics

- Detailed description of a design system that includes identification of key product characteristics, identification of key production processes, balancing of key product design requirements to production process capabilities, identification of key process parameters and verification methods.
- The availability of established and validated process control tools and practices.

Manufacturing Development Guide

Variability Reduction

- Approaches to variability reduction and plans for implementation
- Planned efforts to document process control plans
- Planned efforts to conduct process capability studies and feed results back to the product design
- Planning for key supplier flow-down of VR methods and requirements.
- Metrics used to manage progress on VR implementation

P&P Validation

- The level of product and process validation effort.
- Simulations and incremental verification and validation processes to proof new tools and processes throughout the development cycle.
- The resources available, the maturity of the products and processes involved, and the level of success of other program events.
- Integration of the line proofing effort into the overall risk management effort.
- Plans for providing guidance on ST/STE/SE validation, and the level of product and process validation effort expected from suppliers.
- Identification of key product and process validation activities in the IMP and in risk management planning.

Virtual Manufacturing

- Virtual manufacturing, prototyping, and planning processes to be used in the pre-EMD program phase to ensure the effective early involvement of manufacturing engineering in the IPT design effort.
- Early involvement of virtual manufacturing tools to provide input to production planning and to production risk identification and management.
- Resources and experience needed to execute virtual manufacturing applications for the transition of the concept design into EMD and Production.

Process Control

- Methods for manufacturing process control and implementation of continuous improvement.
- Procedures for continuous collection and review of data to identify improvement opportunities.
- Configuration control procedures to be employed for product design, ST/STE/SE, production methods and plans, and manufacturing planning.

Key Suppliers

Manufacturing Development Guide

- Approach to identification and selection of any new key suppliers, including key suppliers of GFP, along with criteria used to make the determination.
- Integration of key supplier activities, including suppliers of GFP, into the overall program plan, with descriptions of the tasks involved and events (with their exit criteria) to be tracked to assure that supplier activities support overall program performance.
- Processes for evaluation of key supplier performance, including suppliers of GFP (after appropriate contractual mechanisms for relationships with key suppliers of GFP have been put in place.
- Supplier capabilities or training in the use of defect prevention processes and techniques such as variability reduction.
- Contractor processes and practices for the management of supplier schedules and for involvement of key suppliers in IPTs, including key suppliers of GFP in those cases where the GFP supplier's contract with the Government includes the requirement for the GFP supplier to provide support to the Prime Contractor.
- Integration of risk management efforts at key suppliers with the program risk effort.
- Flow-down of performance specification and key process parameters and key product characteristics.

Variability Reduction

- Planned approach to variability reduction and process control, including flow-down to suppliers.
- Metrics used to manage progress on VR implementation

Factory Efficiency

- Demonstration of an ongoing production phase commitment to affordability, and a sensitivity to total acquisition costs, capacity constraints, and industrial base issues.
- Sustainment during the production phase of the open environment created by the IPT processes in the preceding phases of the program.
- Direct participation of manufacturing engineering in the decision processes associated with quality metrics, economic trade studies, and make vs. buy decisions.
- Functioning of the Program Office's manufacturing engineering representative as a member of the IPT, communicating directly with the Program Office with respect to opportunities to improve factory efficiency, contract effectiveness, requirements modifications, schedule changes, and other areas.

Manufacturing Capability Assessment

Manufacturing Development Guide

- Description of proposed Production Planning, Control and Management System
- Planned materials and critical manufacturing processes (including purchased or subcontracted items)
- Existing/planned resources needed to achieve contractual requirements
- Manufacturing Management capabilities

Evaluation Criteria Guidance (Section M)

Manufacturing Engineering's Role in IPPD

Evaluation of an offeror's capability to effectively employ IPPD processes should be based upon:

- An established or proposed IPPD process, including team member roles, responsibilities, and authority.
- Presentation of a viable plan which can reasonably be expected to effectively institutionalize IPPD in the offeror's organization (if the offeror has no previous IPPD experience).
- Data on existing process cost and capabilities and evidence that the data has been used in design trade studies.
- An established, or proposed, demonstration or analytical approach to validate that the process capabilities needed to achieve the stated affordability requirements are within industry standards or identified as cost and schedule risk issues.

Engineering for Affordability and Producibility

- Established practices for cost requirement allocation and cost flow-down.
- Planned implementation of resources and tools for the consideration of cost requirements in the design trade studies.
- Planned use of formal cost avoidance initiatives/programs such as those described above.
- Planned use of cost risk identification/mitigation processes.
- Plans for flowing down to appropriate suppliers cost avoidance initiatives/programs such as those described above.

Quality Systems

- Establishment of capable processes.
- Monitoring and control of critical processes and product variation.
- Establishment of mechanisms for feedback of field product performance.
- Implementation of an effective root cause analysis and corrective action system.

Manufacturing Development Guide

- Continuous process improvement.
- Ensuring effective management of identified risks.
- Integration of technical and management processes and systems.
- Measurement of the effectiveness of processes and systems.
- Training personnel in the use and deployment of state-of-the-art quality tools and techniques.

Development Phase - Section M

Production Cost Modeling

- Robustness of the contractor's processes and procedures for developing and validating a PCM.
- Maturity of the documentation and maintenance practices for configuration control of the PCM.
- Status of the contractor's preliminary model, if available.

Design Trade Studies

- Established processes for performing and documenting design trade studies and the planned integration of design trade studies and results into the IMP.
- Established process for System Specification requirements allocation and flow down.
- Established processes for addressing the ST/STE/SE requirements as part of the design trade study process

Manufacturing Capability Assessment

- Identified process capabilities of the prime and key suppliers, with linkage to process requirements.
- Identified Manufacturing Management components such as Production Planning and Control systems, Production Surveillance and Reporting systems, and Subcontractor Management
- Inclusion of Manufacturing Risks. Addressing of supplier capacity and capability constraints and industrial base sustainment issues. Addressing environmental assessments and environmental impacts.

Key Suppliers

- The disciplined, structured, and defined process for identification and selection of key suppliers.
- The process used for evaluation of key supplier performance.

Manufacturing Development Guide

- Effective methodologies for key characteristics and performance specification flow-down.
- Key supplier experience in (or training plan for) the use of continuous improvement and defect prevention processes and techniques.

Key Characteristics

- The extent to which a disciplined, structured, and demonstrated process is used for requirements allocation and identification of key product characteristics, key process parameters, and product/process matching.
- The availability of established and validated process control tools and practices.

Variability Reduction

- The understanding of VR principles and their planning for implementation
- Planned efforts to document control plans
- Planned efforts to conduct process capability studies and feed results back to the product design
- Extent to which VR requirements are flowed down to suppliers
- The appropriateness of planned metrics for managing processes

P&P Validation

- Incremental verification and validation throughout the design process.
- Integration with the risk management plan.
- Use of simulations for verification and validation in virtual environments.

Virtual Manufacturing

- Demonstrated ability to manage risk through assembly simulation, process flow simulation, and process capability analysis.
- Demonstrated ability to evaluate manufacturing resource requirements and provide schedule credibility through process flow simulation.

Production Phase - Section M

Process Control

- Demonstrated understanding and use of the concepts of manufacturing process control and continuous improvement of manufacturing processes.
- Disciplined approach to controlling manufacturing processes, continuously seeking and identifying opportunities for improvement, and implementing process improvements.

Key Suppliers

Manufacturing Development Guide

- The extent to which a disciplined, structured process is used for the integration of key supplier events/activities into the IMP.
- Effective practices for key process parameters and key product characteristics flow-down to suppliers.
- The extent to which a disciplined, structured, and defined process is used for evaluation of key supplier performance.
- Key supplier experience or training for the use of defect prevention processes and techniques.
- Key supplier risk assessment and risk mitigation planning.

Variability Reduction

- The understanding of VR principles and their planning for implementation
- The appropriateness of planned metrics for managing processes

Factory Efficiency

- Continued reduction of the AUPP for each procurement.
- Development and use of effective contractor and Program Office metrics in order to monitor effectivity and effectiveness of changes to the product and the production processes, ensuring that product performance is not sacrificed in the continuing effort to improve factory efficiency, or vice versa.
- Maintenance of the basic disciplines of change management, revalidation, and reverification of key characteristics.

Manufacturing Capability Assessment

- The Production Planning and Control system is evaluated to assure all pertinent parts will be available when needed. If a new process is proposed, its capability may need to be demonstrated.
- Lists of materials and critical processes are examined to insure that all non-routine materials and critical processes are within the capability of the offeror. These processes and process capabilities are verified. The offeror's understanding and control of subcontractors' capabilities is a must.
- Proposed resources are checked against requirements. Planned resources are investigated for availability.
- Manufacturing management's risk management practices are reviewed, and successful relevant risk mitigation actions are viewed as demonstrated capability.

Appendix III: 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