Manufacturing Readiness Level (MRL) Deskbook

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OSD Manufacturing Technology Program
In collaboration with
The Joint Service/Industry MRL Working Group

This document is not a DOD requirement and is being offered as a Best Practice

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Manufacturing status and risk evaluations have been performed as part of defense acquisition programs for years in a variety of forms. These evaluations, while often highly structured and well managed, did not use a uniform metric to measure and communicate manufacturing risk and readiness. They were not conducted on technology development efforts or in early acquisition phases. Furthermore, the frequency of these types of evaluations has declined since the 1990s. Paralleling this decline, manufacturing-related impacts on cost and schedule have grown.

New policy has been established to address this problem in Department of Defense Instruction 5000.02, *Operation of the Defense Acquisition System*, dated 8 December 2008. It establishes target maturity criteria for measuring risks associated with manufacturing processes at Milestones A, B, and C and Full Rate Production. However, quantitative assessments are necessary to determine whether these criteria have been met.

Manufacturing Readiness Levels (MRLs) and assessments of manufacturing readiness have been designed to manage manufacturing risk in acquisition while increasing the ability of the technology development projects to transition new technology to weapon system applications. MRL definitions create a measurement scale and vocabulary for assessing and discussing manufacturing maturity and risk. Using the MRL definitions, an assessment of manufacturing readiness is a structured evaluation of a technology, component, manufacturing process, weapon system or subsystem. It is performed to:

- Define current level of manufacturing maturity
- Identify maturity shortfalls and associated costs and risks
- Provide the basis for manufacturing maturation and risk management

This document provides best practices for conducting assessments of manufacturing readiness. It is designed for acquisition program managers and managers of those technology development projects and pre-systems acquisition technology demonstration projects intending to transition *directly* to the acquisition community as well as the people who are involved in conducting the assessments.

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1. Introduction

1.1 MANUFACTURING RISKS RECOGNIZED IN POLICY

Manufacturing status and risk evaluations have been performed as part of defense acquisition programs for years in a variety of forms (e.g. Production Readiness Reviews, Manufacturing Management/Production Capability Reviews, etc.).[1] These reviews, while often highly structured and well managed, did not use a uniform metric to measure and communicate manufacturing risk and readiness. They were not conducted on technology development efforts or in early acquisition phases. Furthermore, the frequency of these types of reviews has declined sharply since the 1990s.

Paralleling this decline, manufacturing-related impacts on cost, schedule, and performance have grown. Studies by the Government Accountability Office (GAO) cite a lack of manufacturing knowledge at key decision points as a leading cause of acquisition program cost growth and schedule slippages in major DoD acquisition programs.[2] Consequently, policy has been developed to strengthen the way in which manufacturing issues and risks are considered in the defense acquisition system.

There is a long standing policy on manufacturing-related content of acquisition strategies. Defense Federal Acquisition Regulation Supplement (DFARS) Section 207.105b (Contents of Written Acquisition Plans)[3] mandates specific national technology and industrial base considerations be included in acquisition strategies for major defense acquisition programs as follows:

- An analysis of the capabilities of the national technology and industrial base to develop, produce, maintain, and support such program, including consideration of factors related to foreign dependency
- Consideration of requirements for efficient manufacture during the design and production of the systems to be procured under the program
- The use of advanced manufacturing technology, processes, and systems during the research and development phase and the production phase of the program
- To the maximum extent practicable, the use of contract solicitations that encourage competing offerors to acquire, for use in the performance of the

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1 Manufacturing risk is one element of overall technical risk to the program.

2 *Defense Acquisitions: Assessment of Selected Weapon Programs*, Government Accountability Office (GAO -09-326SP), March 30, 2009. Similar conclusions were made in prior GAO reports issued annually around the same time of the year. These reports may be accessed at http://www.gao.gov/docsearch/agency.php.

3 Sub-Part 207.1, "Acquisition Plans," Defense Federal Acquisition Regulation Supplement (DFARS), revised July 29, 2009; http://www.acq.osd.mil/dpap/dars/dfarspgi/current/index.html.

contract, modern technology, production equipment, and production systems (including hardware and software) that increase the productivity of the offerors and reduce the life-cycle costs

- Methods to encourage investment by U.S. domestic sources in advanced manufacturing technology production equipment and processes through: (i) recognition of the contractor's investment in advanced manufacturing technology production equipment, processes, and organization of work systems that build on workers' skill and experience, and work force skill development in the development of the contract objective; and (ii) increased emphasis in source selection on the efficiency of production.

Department of Defense Instruction (DoDI) 5000.02 establishes *new policy* to address manufacturing over the entire life cycle.[4] In the Materiel Solution Analysis (MSA) Phase, the policy requires the Analysis of Alternatives (AoA) to assess "manufacturing feasibility."[5]

For the Technology Development (TD) Phase, the new policy also affirms that:

- Prototype systems or appropriate component-level prototyping shall be employed to "evaluate manufacturing processes."[6]

- A successful preliminary design review will "identify remaining design, integration, and manufacturing risks."[7]

- A program may exit the TD Phase when "the technology and manufacturing processes for that program or increment have been assessed and demonstrated in a relevant environment" and "manufacturing risks have been identified."[8]

Furthermore, one of the purposes of the Engineering and Manufacturing Development (EMD) Phase is to "develop an affordable and executable manufacturing process."[9] Consequently, the policy goes on to say that: "the maturity of critical manufacturing processes" is to be described in a post-Critical Design Review (CDR) Assessment;[10] System Capability and Manufacturing Process Demonstration[11] shall show "that system production can be supported by demonstrated manufacturing

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4 Department of Defense Instruction (DoDI) 5000.2, Operation of the Defense Acquisition System, Undersecretary of Defense for Acquisition, Technology and Logistics (USD (AT&L)), December 8, 2008.
5 DoDI 5000.02 Enclosure (2) paragraph 4.c.(6).
6 DoDI 5000.02 Enclosure (2) paragraph 5.c.(9).
7 DoDI 5000.02 Enclosure (2) paragraph 5.d.(6).
8 DoDI 5000.02 Enclosure (2) paragraph 5.d.(7).
9 DoDI 5000.02 Enclosure (2) paragraph 6.a.
10 DoDI 5000.02 Enclosure (2) paragraph 6.c.(6).(c).
11 The second sub-phase of EMD.

processes;"[12] and the EMD Phase shall end when "manufacturing processes have been effectively demonstrated in a pilot line environment."[13]

Finally, the policy establishes two entrance criteria for the Production and Deployment Phase as "no significant manufacturing risks" and "manufacturing processes [are] under control (if Milestone C is full-rate production)."[14] This enables Low Rate Initial Production (LRIP) to result in an "adequate and efficient manufacturing capability"[15] so that the following knowledge will be available to support Full-Rate Production (FRP) approval:

- "demonstrated control of the manufacturing process"
- "the collection of statistical process control data"
- "demonstrated control and capability of other critical processes"[16]

1.2 GUIDANCE ISSUED IN SUPPORT OF POLICY

1.2.1 MANUFACTURING-RELATED SUCCESS CRITERIA ESTABLISHED FOR TECHNOLOGY DEVELOPMENT AND ACQUISITION STRATEGIES

In support of both DFARS language and the new 5000.02, the *Defense Acquisition Guidebook*[17] (DAG) Chapter 2 (Acquisition Program Baselines, Technology Development Strategies, and Acquisition Strategies) provides guidance on including manufacturing capabilities and risks in the Technology Development Strategy (TDS) at Milestone A and the Acquisition Strategy (AS) at Milestones B and C. Both the TDS and the AS are information baselines for efforts that continually evolve during the progression through the acquisition system.

The TDS guides the reduction of technology risk, the determination of the appropriate set of technologies to be integrated into a full system, and the demonstration of critical technologies on representative prototypes. Therefore, the results of the required assessments of manufacturing feasibility carried out in conjunction with the AoA become the basis of meeting the success criteria for the Alternative Systems Review (ASR) and important inputs to the TDS.

The TDS should identify and address how industrial capabilities, including manufacturing technologies and capabilities, will be considered and matured during the TD Phase. Industrial capabilities encompass public and private capabilities to design, develop, manufacture, maintain, and manage DoD products. A discussion of these

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[12] DoDI 5000.02 Enclosure (2) paragraph 6.c.(6).(d).
[13] Ibid.
[14] DoDI 5000.02 Enclosure (2) paragraph 7.b .
[15] DoDI 5000.02 Enclosure (2) paragraph 7.c.(1).(a).
[16] DoDI 5000.02 Enclosure (2) paragraph 7.c.(2).
[17] *Defense Acquisition Guidebook*, Defense Acquisition University, December 17, 2009; https://dag.dau.mil/Pages/Default.aspx

considerations is needed to ensure that the manufacturing capability will be assessed adequately, and that reliable, cost-effective, and sufficient industrial capabilities will exist to support the program's overall cost, schedule, and performance goals for the total research and development program.

The AS is a comprehensive, integrated plan that identifies the acquisition approach and describes the business, technical, and support strategies that will be followed to manage program risks and meet program objectives. Therefore, the results of the assessments and demonstrations of the technology and manufacturing processes in a relevant environment and the identification of manufacturing risks that are reflected as success criteria for the Preliminary Design Review (PDR) are important inputs to the Industrial Base Capabilities Considerations that are a required part of the AS at Milestone B. Similarly, the results of the demonstrations of manufacturing processes in a pilot line environment that are reflected as success criteria for the Production Readiness Review (PRR) are important inputs to the Industrial Base Capabilities Considerations that are a required part of the AS at Milestone C.

The development of the AS should include results of industrial base capability (public and private) analysis to design, develop, produce, support, and, if appropriate, restart an acquisition program. This includes assessing manufacturing readiness and effective integration of industrial capability considerations into the acquisition process and acquisition programs. For applicable products, the AS should also address the approach to making production rate and quantity changes in response to contingency needs. Consider the following manufacturing threads in developing the strategy:

- Technology and industrial base capabilities
- Design
- Cost and funding
- Materials
- Process capability and control
- Quality management
- Manufacturing personnel
- Facilities
- Manufacturing management

1.2.2 MANUFACTURING-RELATED SUCCESS CRITERIA ESTABLISHED FOR SYSTEMS ENGINEERING REVIEWS

This DoDI 5000.02 policy is specifically reinforced in the DAG Chapter 4 (Systems Engineering) with the establishment of manufacturing-related success criteria

for the systems engineering technical reviews that occur prior to the acquisition milestones. In addition, the DAG also contains success criteria developed for the technical review that marks the transition between Integrated System Design[18] and System Capability and Manufacturing Process Demonstration. All of these success criteria are presented as questions that should be answered affirmatively.

Success criteria for the ASR[19] prior to Milestone A are as follows:

- Have the preliminary manufacturing processes and risks been identified for prototypes?
- Have required investments for technology development, to mature design and manufacturing related technologies, been identified and funded?
- Have initial producibility assessments of design concepts been completed?

At the PDR prior to Milestone B the following questions apply:

- Have the majority of manufacturing processes been defined and characterized?
- Are initial manufacturing approaches documented?
- Have producibility assessments of key technologies been completed?
- Has a production cost model been constructed?
- Can the industrial base support production of development articles?
- Have long-lead and key supply chain elements been identified?

Exit questions for the CDR prior to System Capability and Manufacturing Process Demonstration include:

- Have the critical manufacturing processes that affect the key characteristics been identified and their capability to meet design tolerances determined?
- Have process control plans been developed for critical manufacturing processes?
- Have manufacturing processes been demonstrated in a production representative environment?
- Are detailed trade studies and system producibility assessments underway?

[18] The first sub-phase of EMD.
[19] Only the PDR and the CDR are required by policy.

- Are materials and tooling available to meet pilot line schedule?
- Has the system production cost model been updated, allocated to subsystem level, and tracked against targets?
- Are long-lead procurement plans in place and has the supply chain been assessed?

The following success criteria are associated with the PRR prior to Milestone C:

- Is the detailed design producible within the production budget?
- Are the production facilities ready and required workers trained?
- Is detail design complete and stable enough to enter low rate production?
- Is the supply chain established and stable with materials available to meet planned low rate production?
- Have manufacturing processes been demonstrated and proven in a pilot line environment?
- Have all producibility trade studies and risk assessments been completed?
- Is the production cost model based upon the stable detailed design and been validated?

1.3 OVERARCHING BEST PRACTICES FOR COMPLYING WITH POLICY AND GUIDANCE

Manufacturing knowledge is necessary to meet DoDI 5000.02 policy requirements and follow the associated DAG guidelines. Manufacturing Readiness Levels (MRLs) and assessments of manufacturing readiness are designed to measure this knowledge. They form the basis for managing manufacturing risk in acquisition while increasing the ability of the technology development projects to transition new technology to weapon system applications.

MRL definitions were developed by a joint DoD/industry working group under the sponsorship of the Joint Defense Manufacturing Technology Panel (JDMTP).[20] The intent was to create a measurement scale that would serve the same purpose for manufacturing readiness as Technology Readiness Levels (TRLs) serve for technology readiness—to provide a common metric and vocabulary for assessing and discussing

[20] *MRL Guide*, Joint Defense Manufacturing Technology Panel Manufacturing Readiness Level Working Group, February 2007; https://acc.dau.mil/GetAttachment.aspx?id=109616&pname=file&aid=24176&lang=en-US.

manufacturing maturity[21] and risk. MRLs were designed with a numbering system to be roughly congruent with comparable levels of TRLs for synergy and ease of understanding and use.

MRLs can serve as a helpful knowledge-based standard and shorthand for evaluating manufacturing maturity, but they must be supplemented with expert professional judgment. Such judgment is provided through an assessment of manufacturing readiness—a structured, fact-based evaluation of a technology, component, manufacturing process, weapon system or subsystem using the MRL definitions. The assessment is performed to:

- Define current level of manufacturing maturity
- Identify maturity shortfalls and associated costs and risks
- Provide the basis for manufacturing maturation and risk management (planning, identification, analysis, mitigation, implementation, and tracking)

The use of MRLs in conjunction with assessments of manufacturing readiness is an industry best practice. A number of major DoD weapon system suppliers and Original Equipment Manufacturers (OEMs) have integrated MRLs into their gated technology transition processes to help decide when a technology is mature enough to use in a product design. As a result, prime contractors and other OEMs are making better decisions about which technologies to include in product designs resulting in reduced cost, schedule and performance risk. Some of the most important benefits include:

- Providing a roadmap, developed by industry and government experts, of the steps necessary to address and implement a mature manufacturing process that will significantly increase the probability of producing a product that meets program objectives of cost, schedule, and performance.
- Identifying where manufacturing maturity is not progressing on schedule and providing management with an assessment of the risk of the situation and the appropriate corrective actions.
- Involving manufacturing subject matter experts and all other relevant stakeholders early in the design and development process in accordance with commercial industry best practices.
- Enabling effective communications between government and industry and the prime contractor and its suppliers.

MRLs are not intended to be an absolute requirement for proceeding into the next phase of acquisition. Therefore MRLs should be tailored for the specific

[21] The terms manufacturing readiness and manufacturing maturity are used interchangeably through this document.

circumstances a program is facing, used to support fact-based decisions, and integrated into the program's risk management process.

1.4 PURPOSE AND ORGANIZATION OF THIS DOCUMENT

Based on lessons learned from work done in DoD and industry, this document describes how MRLs should be used in conducting assessments of manufacturing maturity and suggests how such assessments should be carried out by:

1. Acquisition program managers for all programs of record
2. Managers for all technology development projects and pre-systems acquisition technology demonstration projects intending to transition *directly* to the acquisition community[22]
3. People who are involved in conducting the assessments

The body of this document contains the information listed below.

- A description of the MRLs (Section 2)
- A description of how manufacturing maturity evolves throughout the acquisition management system (Section 3)
- A description of the process for conducting assessments of manufacturing readiness (Section 4)
- A description of manufacturing risk management and the best practices for managing manufacturing maturation (Section 5)
- A description of suggested contract language for implementing MRLs as part of assessments of manufacturing readiness (Section 6)
- A detailed description of desired levels of manufacturing maturity over the acquisition life cycle by MRL thread (Appendix A)
- A list of acronyms (Appendix B)

Additional information, available to industry and government, about the MRL definitions, threads, tutorials, and tools can be found at http://www.dodmrl.com/. This site provides the latest versions of all MRL-related material and has links to short courses and to Air Force training presentations. In addition, training is available on the use of MRLs. The Air Force Institute of Technology has developed a three-day MRL course titled "Assessing Manufacturing Readiness (SYS 213)." The Defense Acquisition University has also embedded MRL training into several of its courses.

[22] These technology development/demonstration projects include all basic and applied research, science and technology, component development, and prototype efforts that are transitioning into an acquisition program.

2. Manufacturing Readiness Levels

2.1 INTRODUCTION

The basic goal of all acquisition programs is to put required capability in the field in a timely manner with acceptable affordability and supportability. To be successful, the two key risk areas of immature product technologies and immature manufacturing capability must be managed effectively. Manufacturing readiness metrics in combination with technology readiness metrics can help acquisition program managers deal with these risks. Similarly, these metrics are important to technology development managers because, they can be used to achieve and convincingly demonstrate a level of readiness for technology transition that acquisition program managers will find credible. Understanding and mitigating these risks will greatly increase the probability of technology insertion for the technology development community and ultimately aid in improvements in cost, schedule and performance for programs of record.

MRLs and TRLs measure these risks. TRLs are described in Section 2.2 along with their overall relationship to MRLs. Section 2.3 defines the MRLs and Section 2.4 is a definition of terms. MRL thread definitions are provided in Section 2.5.

2.2 TRLS AND THEIR RELATIONSHIP TO MRLS

TRLs provide a systematic metric/measurement system to assess the maturity of a particular technology. TRLs enable a consistent comparison of maturity between different types of technology. The TRL approach has been used for many years in the National Aeronautics and Space Administration (NASA) and is the technology maturity measurement approach for all new DoD programs. TRLs have been primarily used as a tool to assist in tracking technologies in development and their transition into production. The nine hardware TRLs are defined as follows:

- TRL 1: Basic principles observed and reported
- TRL 2: Technology concept or application formulated
- TRL 3: Experimental and analytical critical function and characteristic proof of concept
- TRL 4: Component or breadboard validation in a laboratory environment
- TRL 5: Component or breadboard validation in a relevant environment
- TRL 6: System or subsystem model or prototype demonstrated in a relevant environment
- TRL 7: System prototype demonstration in an operational environment

- TRL 8: Actual system completed and "flight qualified" through test and demonstration

- TRL 9: Actual system "flight proven" through successful mission operations

Manufacturing readiness and technology readiness go hand-in-hand. MRLs, in conjunction with TRLs, are key measures that define risk when a technology or process is matured and transitioned to a system. It is quite common for manufacturing readiness to be paced by technology readiness or design stability. Manufacturing processes will not be able to mature until the product technology and product design are stable. MRLs can also be used to define manufacturing readiness and risk at the system or subsystem level. For those reasons, the MRL definitions were designed to include a nominal level of technology readiness as a prerequisite for each level of manufacturing readiness.

2.3 MANUFACTURING READINESS LEVEL DEFINITIONS

There are ten MRLs (numbered 1 through 10) that are correlated to the nine TRLs in use. The final level (MRL 10) measures aspects of lean practices and continuous improvement for systems in production.

MRL 1: Basic Manufacturing Implications Identified

This is the lowest level of manufacturing readiness. The focus is to address manufacturing shortfalls and opportunities needed to achieve program objectives. Basic research (i.e., funded by budget activity) begins in the form of studies.

MRL 2: Manufacturing Concepts Identified

This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs. Typically this level of readiness includes identification, paper studies and analysis of material and process approaches. An understanding of manufacturing feasibility and risk is emerging.

MRL 3: Manufacturing Proof of Concept Developed

This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. This level of readiness is typical of technologies in Applied Research and Advanced Development. Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.

MRL 4: Capability to produce the technology in a laboratory environment

This level of readiness acts as an exit criterion for the Materiel Solution Analysis (MSA) Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. At this point, required investments, such as manufacturing technology development, have been identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks have been identified for building prototypes and mitigation plans are in place. Target cost objectives have been established and manufacturing cost drivers have been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.

MRL 5: Capability to produce prototype components in a production relevant environment

This level of maturity is typical of the mid-point in the Technology Development Phase of acquisition, or in the case of key technologies, near the mid-point of an Advanced Technology Demonstration (ATD) project. Technologies should have matured to at least TRL 5. The industrial base has been assessed to identify potential manufacturing sources. A manufacturing strategy has been refined and integrated with the risk management plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts have been initiated or are ongoing. Producibility assessments of key technologies and components are ongoing. A cost model has been constructed to assess projected manufacturing cost.

MRL 6: Capability to produce a prototype system or subsystem in a production relevant environment

This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the Engineering and Manufacturing Development (EMD) Phase of acquisition. Technologies should have matured to at least TRL 6. It is normally seen as the level of manufacturing readiness that denotes acceptance of a preliminary system design. An initial manufacturing approach has been developed. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. However, preliminary design has been completed and producibility assessments and trade studies of key technologies and components are complete. Prototype manufacturing processes and technologies, materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a

production relevant environment. Cost, yield and rate analyses have been performed to assess how prototype data compare to target objectives, and the program has in place appropriate risk reduction to achieve cost requirements or establish a new baseline. This analysis should include design trades. Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been completed. Long-lead and key supply chain elements have been identified.

MRL 7: Capability to produce systems, subsystems, or components in a production representative environment

This level of manufacturing readiness is typical for the mid-point of the Engineering and Manufacturing Development (EMD) Phase leading to the Post-CDR Assessment. Technologies should be on a path to achieve TRL 7. System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. The cost model has been updated with detailed designs, rolled up to system level, and tracked against allocated targets. Unit cost reduction efforts have been prioritized and are underway. Yield and rate analyses have been updated with production representative data. The supply chain and supplier quality assurance have been assessed and long-lead procurement plans are in place. Manufacturing plans and quality targets have been developed. Production tooling and test equipment design and development have been initiated.

MRL 8: Pilot line capability demonstrated; Ready to begin Low Rate Initial Production

This level is associated with readiness for a Milestone C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is complete and sufficiently stable to enter low rate production. All materials, manpower, tooling, test equipment and facilities are proven on pilot line and are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment and are under control and ready for low rate production. Known producibility risks pose no significant challenges for low rate production. Cost model and yield and rate analyses have been updated with pilot line results. Supplier qualification testing and first article inspection have been completed. The Industrial Capabilities Assessment for Milestone C has been completed and shows that the supply chain is established to support LRIP.

MRL 9: Low rate production demonstrated; Capability in place to begin Full Rate Production

At this level, the system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation. Materials, parts, manpower, tooling, test equipment and facilities are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement.

MRL 10: Full Rate Production demonstrated and lean production practices in place

This is the highest level of production readiness. Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements. Rate production unit costs meet goals, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements are ongoing.

Although the MRLs are numbered, the numbers themselves are unimportant. The numbers represent a non-linear ordinal scale that identifies what maturity should be as a function of where a program is in the acquisition life cycle (as described in Section 3). Using numbers is simply a convenient naming convention.

2.4 DEFINITION OF TERMS

As manufacturing readiness increases, demonstration of manufacturing capabilities should be accomplished in more realistic environments. Prior to Milestone A, the MRLs focus on manufacturing feasibility by identifying and reducing the production risk of the proposed concepts. These proposed technology concepts are generally demonstrated in a laboratory environment. MRLs focus on identifying manufacturing challenges that should be addressed in the TD phase.

Prior to Milestone B, MRLs focus on a contractor's capability to produce prototypes in a production relevant environment, outside of the laboratory. The parameters defining a production relevant environment should be based on the risks

and uniqueness associated with demonstrating that contractors' key processes meet program requirements.

A production relevant environment represents the manufacturing capability needed to proceed into the EMD Phase with high confidence of achieving program cost, schedule and performance requirements. This level of production realism is well beyond what is seen in a laboratory. The emphasis is on addressing higher risk areas (e.g. more advanced technologies and newer manufacturing capabilities). During this critical junction it is essential that the contractor(s) demonstrate the capability to build the product or a similar product (e.g. size, tolerances, quality levels, processes, and testing) in the facility intended to be used during production.

> **Production relevant environment**—An environment with some shop floor production realism present (such as facilities, personnel, tooling, processes, materials etc.). There should be minimum reliance on laboratory resources during this phase. Demonstration in a production relevant environment implies that contractor(s) must demonstrate their ability to meet the cost, schedule, and performance requirements of the EMD Phase based on their production of prototypes. The demonstration must provide the program with confidence that these targets will be achieved, but does not require a production line. Furthermore, there must be an indication of how the contractor(s) intend to achieve the requirements in a production representative and pilot environments.

As a program evolves through the EMD phase and hardware is built for qualification testing, the manufacturing processes should become more robust and mature to address production representative activities on the whole program.

> **Production representative environment**—An environment that has as much production realism as possible, considering the maturity of the design. Production personnel, equipment, processes, and materials that will be present on the pilot line should be used whenever possible. The work instructions and tooling should be of high quality, and the only changes anticipated on these items are associated with design changes downstream that address performance or production rate issues. There should be no reliance on a laboratory environment or personnel.

The final stage of EMD is producing products that look and operate like they are production units from LRIP. These units need to be built on a pilot production line to adequately demonstrate the ability to migrate from EMD to LRIP. Without this realism it would be very difficult to obtain confidence that the production process will be able to meet cost, schedule, and performance (e.g. quality) requirements for production.

> **Pilot line environment**—An environment that incorporates all of the key production realism elements (equipment, personnel skill levels, facilities, materials, components, work instructions, processes, tooling, temperature, cleanliness, lighting etc.) required to manufacture production configuration items, subsystems or systems that meet design requirements in low rate production. To

the maximum extent practical, the pilot line should utilize full rate production processes.

The definitions of relevant, representative, and pilot line environments are intended to demonstrate the natural progression of manufacturing maturity throughout the acquisition life cycle. The program office and contractor must reach agreement on the detailed production realism content (equipment, personnel skill levels, processes, etc.) for each definition above. This agreement must be based on the specific situation and its associated manufacturing risk in order to mitigate that risk in a timely and thorough manner.

Two other definitions are germane to this discussion.

Manufacturability—The characteristics considered in the design cycle that focus on process capabilities, machine or facility flexibility, and the overall ability to consistently produce at the required level of cost and quality. Associated activities may include some or all of the following:

- Design for commonality and standardization—uses fewer parts
- Design for environmental and safety compliance
- Design for multi-use and dual-use applications
- Design for modularity and plug compatible interface/integration
- Design for flexibility/adaptability or use “robust design”
- Utilize reliable processes and materials
- Utilize monolithic and determinant assembly
- Design for manufacturing and assembly
- Achieve production yield

Producibility—The relative ease of producing an item that meets engineering, quality and affordability requirements. Associated activities may include some of the following:

- Design for specific process capability and control parameters
- Perform material characterization analysis
- Perform variable reduction analysis, e.g., Taguchi and design of experiments

- Develop critical materials and processes before selecting product design
- Utilize modeling and simulation for product and process design tradeoffs
- Design and development of closed-loop process control on critical items

2.5 MRL THREADS AND SUB-THREADS

Successful manufacturing has many dimensions. MRL threads have been defined to organize these dimensions into nine manufacturing risk areas. The threads are as follows:

- **Technology and the Industrial Base:** Requires an analysis of the capability of the national technology and industrial base to support the design, development, production, operation, uninterrupted maintenance support of the system and eventual disposal (environmental impacts).
- **Design:** Requires an understanding of the maturity and stability of the evolving system design and any related impact on manufacturing readiness.
- **Cost and Funding:** Requires an analysis of the adequacy of funding to achieve target manufacturing maturity levels. Examines the risk associated with reaching manufacturing cost targets.
- **Materials:** Requires an analysis of the risks associated with materials (including basic/raw materials, components, semi-finished parts, and subassemblies).
- **Process Capability and Control:** Requires an analysis of the risks that the manufacturing processes are able to reflect the design intent (repeatability and affordability) of key characteristics.
- **Quality Management:** Requires an analysis of the risks and management efforts to control quality, and foster continuous improvement.
- **Manufacturing Workforce (Engineering and Production):** Requires an assessment of the required skills, availability, and required number of personnel to support the manufacturing effort.
- **Facilities:** Requires an analysis of the capabilities and capacity of key manufacturing facilities (prime, subcontractor, supplier, vendor, and maintenance/repair).

- **Manufacturing Management:** Requires an analysis of the orchestration of all elements needed to translate the design into an integrated and fielded system (meeting Program goals for affordability and availability).

Many of the MRL threads have been decomposed into sub-threads. This enables a more detailed understanding of manufacturing readiness and risk, thereby ensuring continuity in maturing manufacturing from one level to the next. For example:

- Technology and the Industrial Base includes industrial base issues and manufacturing technology development
- Design includes producibility and maturity
- Cost and Funding includes production cost knowledge (cost modeling), cost analysis, and manufacturing investment budget
- Materials includes maturity, availability, supply chain management, and special handling (i.e. government furnished property, shelf life, security, hazardous materials, storage environment, etc.)
- Process Capability and Control includes modeling and simulation (product and process), manufacturing process maturity, and process yields and rates
- Quality Management includes supplier quality
- Manufacturing Management includes manufacturing planning and scheduling, materials planning, and tooling/special test and inspection equipment

The matrix shown in Appendix A provides detailed criteria for each of the ten MRLs, by thread and sub-thread, throughout the acquisition life cycle. The matrix allows a user to separately trace and understand the maturation progress of each of the threads and sub-threads as readiness levels increase from MRL 1 though MRL 10. These thread and sub-thread MRL criteria should be applied when appropriate to the situation and may be tailored to a particular technology or application.

As stated earlier, the MRL numbering scheme is not important for assessments of manufacturing readiness. The degree of maturity of an element of a program that is being assessed, whether the target maturity has been achieved, and what has to be accomplished to increase maturity *are* important. This information is discovered in the assessment process using the matrix in Appendix A, not by assigning a number to the element being assessed.

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3. MRLs and the Acquisition Management System

3.1 INTRODUCTION

Manufacturing risk management plays an integral part in the acquisition of all weapon systems *throughout their entire life cycle.*[23] MRLs should be used in source selection to assess the manufacturing maturity and risk of each offer. If multiple prototypes are used in a down-select process for the next phase of acquisition, MRL-based assessments should be performed on each configuration to provide critical knowledge of manufacturing maturity and risk of each prototype. Delivering weapon systems in a timely and cost-effective manner is not possible if these risks are not well managed.

Manufacturing risk management is based on an understanding of the reasons why systems did not meet MRL-targets and a determination of the associated impact throughout the life cycle. This effort highlights areas needing management attention and helps ensure successful execution and transition of the program/project[24] into the next phase. When targets are not met, the program should develop and implement a Manufacturing Maturation Plan (MMP)[25] to ensure that the appropriate level of maturity will be achieved at the next decision point.

While MRLs show a natural progression of manufacturing maturity throughout the acquisition life cycle, the progressions are not all equal. That is why *focusing on MRL numbers is a poor practice*. There may be significant risks in achieving the next level of maturity even when a program is maturing on schedule. Although assessments of manufacturing readiness assist a program to effectively and efficiently mature the manufacturing process, they must be integrated with program objectives and constraints within the overall systems engineering environment. In addition, MRLs can increase or decrease as a result of changes to the facility, processes, suppliers, design, etc. Such changes do not necessarily mean greater or lesser risk. For example, lowering the current MRL might be driven by implementing a major producibility improvement that will save millions of dollars and even reduce risk.

A common question is the return on investment for conducting MRL-based assessments of manufacturing readiness. The investment to conduct effective assessments and manage the identified risks should be part of a company's or program office's standard operating procedures. Unfortunately, the return on that investment is

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[23] The acquisition life cycle is defined by the acquisition management system.

[24] The term "program" refers to an acquisition program of record. The term "project" refers to any technology development effort (ranging from basic research to advanced component development and prototypes) prior to the establishment of a program of record in the acquisition life cycle even though an acquisition program office is often formed prior to that point in time.

[25] The MMP addresses the manufacturing risk and provides a mitigation plan for each risk area. See section 5 of this deskbook.

very difficult to quantify just like any other risk category (e.g., it is not possible to determine a return on investment for a failure modes and effects analysis). Although the return on investment cannot be effectively quantified, a program cannot afford to ignore manufacturing risk because the consequences are too severe. Conducting MRL-based assessments of manufacturing readiness is an effective way to ensure risks are identified and managed as early as possible.

Section 1 of this deskbook discussed manufacturing-related requirements at Milestones and associated systems engineering technical reviews. The criteria for meeting those requirements correlate with MRL targets. Figure 3-1 indicates the nominal relationship between MRL targets and the acquisition life cycle.

This section is organized around the acquisition life cycle. Section 3.2 discusses manufacturing readiness during pre-systems acquisition and section 3.3 covers systems acquisition.

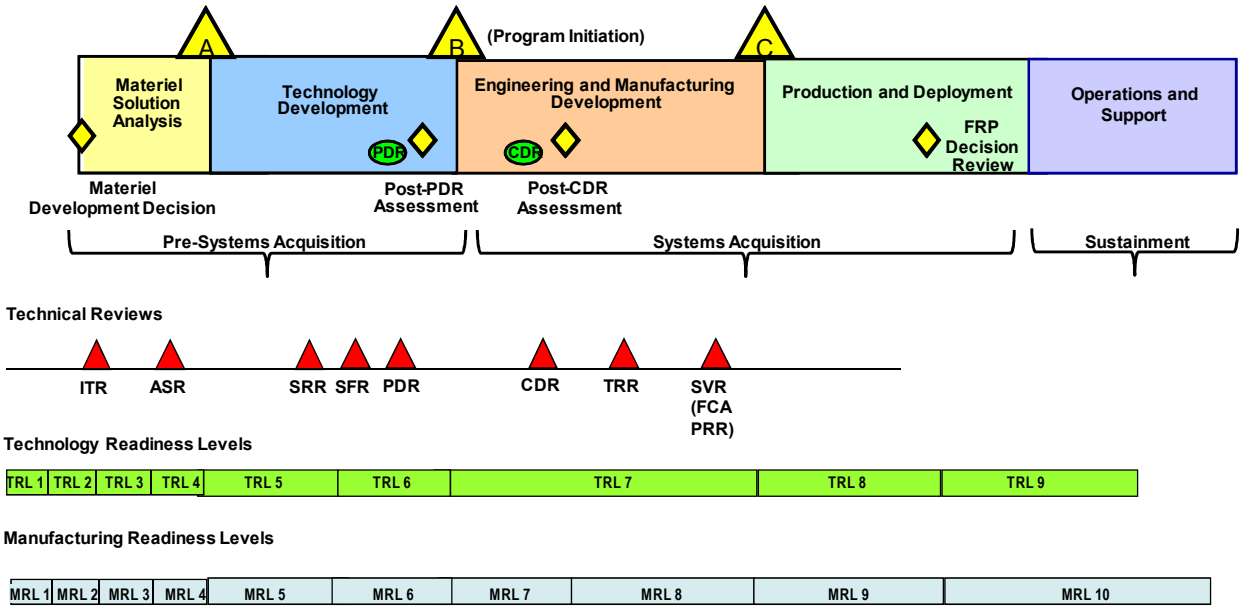

Figure 3-1. Relationship of MRLs to System Milestones, TRLs, and Technical Reviews

3.2 MANUFACTURING READINESS DURING PRE-SYSTEMS ACQUISITION

Pre-systems acquisition occurs before Milestone B. It ends with a decision to initiate a program of record[26] that is based upon the transition of mature technologies with manageable risk. Thus, the acquisition community expects that labs will provide technology mature enough to transition smoothly (i.e. meet cost, schedule and performance requirements) into designs.

For all technology development project managers, consideration of manufacturing risk and issues should begin early in TD and intensify as the technology

[26] An acquisition program that has been formally initiated by the Milestone Decision Authority and has been fully funded throughout the Future Years Defense Plan.

matures so that manufacturing maturity is sufficient at the time of transition to support rapid and affordable incorporation into a system. Some manufacturing-related best practices for technology development project managers are as follows:

- Plan and fund to ensure that both the target MRL and the target TRL are achieved within budget at transition
- Perform a baseline assessment of manufacturing readiness early in the program to establish a starting MRL and include the transition customer in this process
- Use the results of the baseline assessment to set priorities and develop an MMP that will reach the target MRL in time to support transition
- Work with transition customers to identify the target MRL that will be acceptable for transition (e.g., MRL 6 at Milestone B) and include this information in the Technology Transition Agreement
- Perform a final assessment of manufacturing readiness to confirm that the target MRL has been reached and include the transition customer in this process
- Include manufacturing subject matter experts in all systems engineering technical reviews

3.2.1 MATERIEL SOLUTION ANALYSIS PHASE

The Materiel Development Decision marks the start of the MSA Phase. This presents the first substantial opportunity to influence systems design by balancing technology opportunities, schedule constraints, funding availability, system performance parameters, and manufacturing feasibility. The technical approach for system development should be driven by knowledge of the manufacturing maturity and risk of the various technologies under consideration as well as their associated performance maturity. Two systems engineering reviews, the Alternative Systems Review (ASR) and the Initial Technical Review (ITR), should be conducted during MSA.

This phase refines the initial concept by conducting an AoA to examine potential materiel solutions with the goal of identifying the most promising option that satisfies the capability need. An AoA is a comparison of the operational effectiveness, suitability, and life-cycle cost of alternatives. The AoA also plays a role in crafting a cost-effective and balanced evolutionary acquisition strategy.

MSA ends when the AoA is complete and a draft TDS has been developed for the proposed materiel solution. The rationale for the proposed evolutionary acquisition strategy would be documented as part of the TDS. Manufacturing subject matter experts should participate in the AoA and the development of the TDS.

During the MSA Phase, an assessment of manufacturing readiness is conducted for each competing materiel solution being examined in the AoA with special emphasis on the proposed materiel solution to analyze feasibility from a manufacturing perspective and determine manufacturing resources needed. It is in effect a manufacturing feasibility assessment. Sources of data may include technology and mission area plans and roadmaps, market research, and early evaluations of technology maturity. Key considerations include:

- Identification of manufacturing technologies and processes not currently available and risks associated with advanced development
- Production feasibility
- Cost and schedule impact analyses to support trade-offs among alternatives
- DoD investments needed to create new industrial capabilities
- Risks of industry not being able to provide new program performance capabilities at planned cost and schedule

The results of the assessment are key emphasis areas for the ASR because the ASR highlights all technical issues that should be considered at the Milestone A Defense Acquisition Board (DAB) selection of the preferred approach. The ASR is conducted near the end of the AoA process. It ensures that the one or more proposed materiel solution(s) are cost effective, affordable, operationally effective and suitable, and can be developed to provide a timely solution to a need at an acceptable level of risk. As such, manufacturing-related readiness criteria should be addressed during this review and manufacturing risk associated with each of the alternatives should be identified. MRL 4 is the target level of maturity. Risk is based on whether the alternatives have achieved that level and the degree of difficulty for advancing to MRL 6 during TD.

The ASR should also identify key system elements that two or more competing teams will prototype after Milestone A. The intent is to reduce technical risk, validate designs, validate cost estimates, evaluate manufacturing processes, and refine requirements. The most feasible and representative materials, manufacturing processes and facilities should be used to produce prototypes.

Prior to Milestone A, a TDS is developed for a proposed materiel solution determined by the ASR. Because time will elapse between the assessment of manufacturing readiness conducted during the AoA and Milestone A, it may be necessary to update or increase the rigor of the assessment of manufacturing readiness of the proposed materiel solution so the most up-to-date information will be used for the TDS and the Milestone A DAB meeting. This is important because that information will be the basis of the Milestone Decision Authority's (MDA's) decision.

Other important outputs of the assessment of manufacturing readiness of the proposed materiel solution include inputs to the following:

- Investments required for manufacturing technology projects
- Definition of development increments
- Systems engineering reviews during TD
- Systems Engineering Plan
- Risk reduction plans
- Quality plans
- Contracting strategy for TD
- Program management reviews during TD

3.2.2 TECHNOLOGY DEVELOPMENT PHASE

The Milestone A decision point marks the entry into the TD Phase of acquisition. TD is a focused effort to mature, prototype, and demonstrate technologies in a relevant environment. The purpose of this phase is to reduce technology risk and to determine the appropriate set of product technologies and manufacturing capabilities to be integrated into a full system. Three major systems engineering reviews are normally conducted during this phase, the System Requirement Review (SRR), the System Functional Review (SFR), and the Preliminary Design Review (PDR).

A Technology Readiness Assessment (TRA) is completed just prior to Milestone B. When feasible, this TRA should be closely coordinated with the assessment of manufacturing readiness conducted at that time. Manufacturing subject matter experts should participate in the TRA process.

TD ends in a decision on the preferred system concept that provides a low risk entry into EMD. Just as it is expected that technologies will be brought to TRL 6 or better by the end of this phase, manufacturing capabilities should also be brought to at least MRL 6.

At the end of the TD Phase, an assessment of manufacturing readiness is conducted to baseline needed industrial capabilities and identify remaining required investments for every competing design or prototype that has conducted a PDR at the full system level. It is in effect a manufacturing capability assessment. Sources of data may include the results of SRR, SFR and incremental PDRs, ICAs, program risk management plans, and the TRA.

While it is not expected that contractors would have a complete factory and supply chain established this early in a program, key knowledge must be obtained on

critical manufacturing processes, production scale-up efforts, and potential supply chain issues. The results of the assessment of manufacturing readiness performed during the MSA Phase should be used as a baseline reference for this activity. It is possible that some technology development activities were not assessed during the MSA Phase. In that case, it is a best practice to conduct an assessment early in the TD Phase to establish a baseline if manufacturing risk is great enough to warrant the effort. Technology Transition Agreements should be used to manage the transition process from a manufacturability and producibility standpoint. Technologies identified to have a maturity level less than MRL 4 at the start of this phase require special attention for maturation and risk mitigation in order to bring them to MRL 6 by Milestone B.

Key considerations for the assessment at the end of the TD Phase include:

- Manufacturing processes and techniques not currently available
- Probability of meeting the delivery date (e.g., for prototypes)
- Design producibility risks
- Potential impact of critical and long-lead time material
- Production equipment availability
- Production unit cost goal realism
- Manufacturing capability and cost and schedule impact analyses to support trade-offs among alternatives
- Recommendations for anticipated production testing and demonstration efforts
- Methods for conserving critical and strategic materials and reducing reliance on foreign sources

The output of the assessment is the basis for knowledge of manufacturing maturity and risk for all technology under development. This is a vital part of the decision process at Milestone B. Therefore, the assessment results must indicate the key emphasis areas for the PDR. This technical review ensures that the system under review has a reasonable expectation of satisfying the requirements within the currently allocated budget and schedule. It produces a report detailing all technical risk and therefore is a key input to the Milestone B DAB (or equivalent) meeting that initiates a program of record. The assessment of manufacturing readiness provides input for selection criteria for the preferred prototype or competing design if applicable by highlighting if and where any risk areas fall short of MRL 6; discussions of the risks that these shortfalls pose to the program; and discussions of the status of efforts to mitigate those risks.

If any risk areas are found to fall short of MRL 6, three basic choices are available to the program manager:

- Request a delay in the Milestone B decision point to allow time to reduce the manufacturing risk
- Select alternative, lower risk manufacturing approaches
- Carry higher manufacturing risk into the Milestone B DAB meeting and submit a MMP. The plan should include funding requirements.

Other important outputs of the assessment of manufacturing readiness include inputs to the following:

- Investments in long-lead items
- Design reviews during EMD
- ICA and the AS
- Systems Engineering Plan
- PDR report
- Risk management plans
- Contracting strategy for EMD
- Quality plan updates
- Manufacturing plans
- Program management reviews during EMD

3.3 MANUFACTURING READINESS DURING SYSTEMS ACQUISITION

The systems acquisition phase that begins after Milestone B encompasses all detailed design and manufacturing activities needed to deliver the requirements defined in the Capability Development Document (CDD) and later the Capability Production Document (CPD). It ends after an FRP decision has been made and sufficient quantities have been fielded to carry out their mission. By considering manufacturing risks and issues in pre-systems acquisition, a strong foundation will be formed for mitigating those risks in systems acquisition. The effect of addressing manufacturing maturity progression in this phase will have significant impact on the programs ability to forecast and achieve the cost, schedule, and overall quality requirements, of the products, as they transition into our warfighters' hands. Some manufacturing-related best practices for acquisition program managers are as follows:

- Plan and fund to ensure that the target MRLs at CDR, Milestone C, and FRP are achievable within budget

- For any element not assessed in the TD Phase, perform an initial assessment of manufacturing readiness to baseline what the risks are and what efforts are needed to achieve future MRL targets

- Use the baseline information to set priorities and develop an MMP that will reach the target MRL in time to support low rate and full rate production

- Incorporate the management of achieving the target MRLs into the program management process (e.g. similar to tracking cost and schedule activities) to ensure adequate progress is being made

- Perform a final assessment of manufacturing readiness to confirm that the target MRL has been reached and that the program is ready to transition to the next phase

- Develop and implement a fully funded MMP to reduce risk to acceptable levels in cases where the targeted MRLs have not been achieved

- Include manufacturing subject matter experts in all systems engineering technical reviews

- Present results of efforts to mature the manufacturing processes to the targeted MRL levels to all key decision makers in the acquisition management system

3.3.1 ENGINEERING AND MANUFACTURING DEVELOPMENT PHASE

Milestone B determines whether a formal acquisition program will be launched and marks the entry point into the EMD Phase. This phase completes the development of a system, leverages design considerations, completes full system integration, develops affordable and executable manufacturing processes, and completes system fabrication, test and evaluation. The systems engineering reviews normally conducted during this phase are the CDR, the Test Readiness Review (TRR), the System Verification Review (SVR) (Functional Configuration Audit) and the PRR.

From a manufacturing perspective, the purpose of the EMD phase is to ready the acquisition program for production by implementing manufacturing risk reduction activities that are reflected in the acquisition strategy. The basic manufacturing planning that was developed in the previous phase should be detailed in EMD and significant program emphasis should be placed on bringing all hardware to the target MRL prior to the decision point at which this phase ends—the authorization to enter LRIP or FRP for non-major systems that do not require LRIP. MRL 8 is the target for LRIP and MRL 9 is the target for FRP; these targets should be reflected in the acquisition program baseline.

During EMD, assessments of manufacturing readiness are conducted to identify remaining risks on the design and manufacturing maturity prior to a production decision. These are manufacturability assessments and should be conducted in concert with the CDR and also later in EMD just prior to the Milestone C decision. Sources of data may include technical reviews and audits, Program Support Reviews, pre-award surveys, incremental PRRs, ICAs, trade-off studies, tooling plans, make-or-buy plans, manufacturing plans, and bills of material.

The results of the assessment of manufacturing readiness performed at the end of the TD Phase will be used as a baseline reference for this activity. The assessment should focus on program-wide manufacturing risks such as fabrication, assembly, integration and test operations; the supply chain performance; the maturity of manufacturing planning; the maturity of manufacturing management systems; adequacy of funding for manufacturing risk reduction efforts and other factors defined in MRL thread descriptions. Articles manufactured on a pilot line during EMD should be made using production materials, components, tooling, facilities and personnel. Key considerations include:

- Industrial base viability
- Probability of meeting the delivery date (e.g., for qualification units)
- Design stability
- Process maturity
- Manufacturing costs
- Supply chain management
- Quality management
- Facilities
- Manufacturing skills availability

The output of the assessment at CDR should be included in the CDR Report to the MDA. This assessment assures that adequate progress is being made toward Milestone C targets. It should identify any area where MRL 7 has not been achieved and determine the efforts necessary to mitigate the associated risks.

The program-level PRR is a Systems Engineering technical review at the end of EMD that determines if a program is ready for production. The PRR assesses whether the prime contractor and major subcontractors have completed adequate production planning and that there are no unacceptable risks for schedule, performance, cost, or other established criteria. An assessment of manufacturing maturity and risk, conducted by manufacturing subject matter experts, should be a principal area of

emphasis during the PRR. That portion of the PRR should review the readiness of the manufacturing processes, the quality management system, and the production planning (i.e., facilities, tooling and test equipment capacity, personnel development and certification, process documentation, inventory management, supplier management, etc.).

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

If any key aspects of the overall program manufacturing preparation are found to fall short of MRL 8/9, there are three basic choices available to an acquisition program manager:

- Request a delay in the Milestone C/FRP decision point to reduce manufacturing risk
- Select an alternative design that would use a lower risk manufacturing approach
- Carry higher manufacturing risk into the Milestone C/FRP review and submit a MMP along with the results of the assessment of manufacturing readiness

Other important outputs of the assessment of manufacturing readiness include inputs to the following:

- Risk management plans
- Quality plan updates
- Manufacturing plan updates
- Systems Engineering Plan
- Contracting strategy for production
- ICAs and the AS
- Program management reviews after Milestone C

3.3.2 PRODUCTION AND DEVLEOPMENT PHASE

At Milestone C the decision is made as to whether the program will proceed into the Production and Deployment Phase. The purpose of the Production and Deployment Phase is to achieve an operational capability that satisfies mission needs. A program may be structured with either one or two major decision points for this phase. The MDA

for Milestone C will decide if the program will enter LRIP or FRP. The target MRL for LRIP is 8 while the target is 9 for FRP.

If LRIP is required, to the extent practical, this production effort should be performed in a manner that uses designs, tooling, materials, components, facilities, and personnel that are representative of the FRP environment. The FRP decision requires that manufacturing risk is understood and that the manufacturing processes for the system be capable, in control, and affordable. Prior to the FRP decision, a manufacturing readiness assessment should be conducted to ensure any outstanding risks will not impact the programs ability to deliver FRP requirements.

Assessments of manufacturing readiness may be used to capture manufacturing product documentation. It is a best practice to incorporate the preservation of such manufacturing product technical data packages in the Data Management Strategy.

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4. The Process for Conducting Assessments of Manufacturing Readiness

4.1 INTRODUCTION

This section provides general guidance and describes best practices for performing assessments of manufacturing readiness. It is organized around the key steps in the process as shown in Figure 4-1.

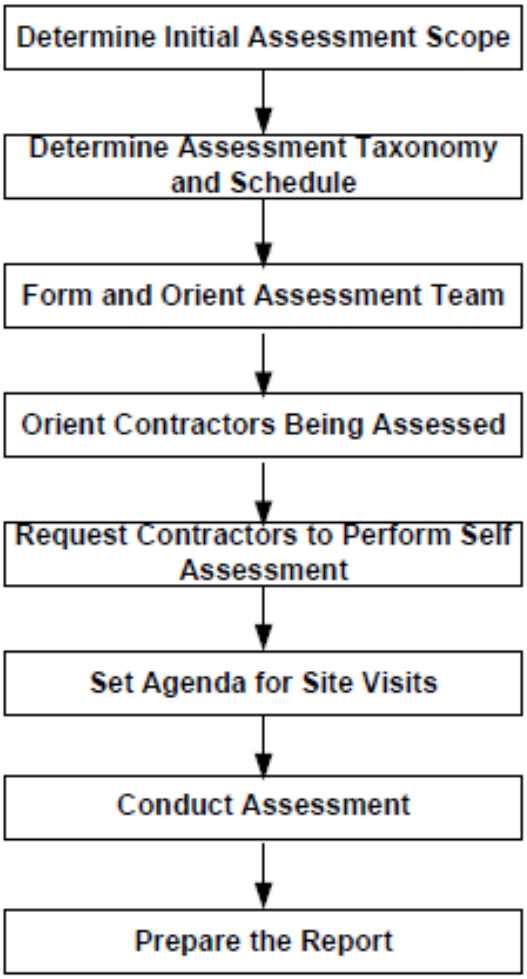

Figure 4-1. Sample Process Flow for Conducting an Assessment of Manufacturing Readiness

An assessment of manufacturing readiness is an important tool for evaluating manufacturing maturity and risk that is most useful in the context of a broader manufacturing risk management process. These assessments should lead to actions

such as: setting goals for increased manufacturing maturity and reduced manufacturing risk; creating action plans and funding estimates to reach those goals; reaching decisions about the readiness of a technology or process to transition into a system design or onto the factory floor; and reaching decisions on a system's readiness to proceed into the next acquisition phase. Therefore, an assessment of manufacturing readiness should compare the status of the key program elements to a nominal MRL appropriate for the stage of the program, describe the risk associated with elements that fall short of the goal, and lay the foundation for manufacturing risk mitigation planning and investment.

4.2 DETERMINE INITIAL ASSESSMENT SCOPE

The government program/project office should establish the initial scope and schedule for the assessment in conjunction with the prime contractor or equivalent thereof.

- At Milestone A, the proponents of the alternatives evaluated in the AoA, including the proposed materiel solution, should fulfill the role of the prime contractor. Since the AoA is conducted by an entity independent of the program, the program/project office may not be established this early in the acquisition process. In that case, the DoD Component should identify who will carry out the program/project office's responsibilities associated with the assessment of manufacturing readiness.

- At Milestone B, there will be prime contractors associated with every system-level preliminary design still in competition. However, there may be circumstances where the system-level preliminary design is not the starting point for the detailed design effort in EMD because a new technology has become available or there has been a change in the requirement. Therefore, assessments of manufacturing readiness are also applicable to the prime contractors associated with these situations if the risk warrants it.

- At CDR, there will be a prime contractor associated with the detailed design.

- At Milestone C, the prime contractor will be associated with the system-level PRR.

- At FRP, there will be a prime contractor associated with production.

Program/project personnel are likely to need training and additional information. The MRL definitions, threads, tutorials, tools and other information can be found at http://www.dodmrl.com/.

The scope of the assessment and the associated MRL target will vary as a function of the stage of the life cycle[27] and specific program requirements. For example,

[27] Section 3 of this deskbook provided guidelines for expectations at key decision points in the acquisition management system.

one would not expect the same manufacturing maturity requirements for a low rate production item (e.g., satellite) as compared to a high rate production program (e.g., ammunition, radios). However, in both cases there should be an adequate demonstration of manufacturing maturity, albeit different specific requirements, to ensure the program can achieve the cost, schedule, and performance requirements at the next level. The MRL process recognizes the uniqueness of every program and consequently it may not be cost effective to achieve the entire MRL target. However, it is essential that the uniqueness of the situation be assessed and agreed upon by key decision makers and that the risk is well understood before proceeding. Some examples that demonstrate how the scope may change are as follows:

- During the MSA Phase an assessment may be conducted for a particular prototype conceptual design in the context of an AoA. Early consideration of producibility and affordability of a particular concept allows for adjustments to design margins before expensive testing or commitment to the achieved performance makes those changes irreversible. It also helps identify manufacturing technologies/capabilities that need to be developed in the next phase. The nominal MRL target would be 4 as an entrance criterion for Milestone A.

- In the early stages of TD, an examination of the producibility of a proposed design allows for trades on cost, performance, and schedule to be accomplished when it is significantly easier to make changes and where changes potentially have a greater impact on key performance metrics. The nominal MRL target would be in the range of 4 to 5.

- In a source selection for EMD, assessments can aid in determining the maturity of the design relative to the offeror's ability to achieve projected cost or schedule targets. The assessment would define manufacturing progress and risk for the next phase and ensure prototype hardware was produced in a relevant environment. The nominal MRL target would be 6 as an entrance criterion for Milestone B.

- At CDR, it is necessary to examine integration processes such as assembly, installation, and test. When a subsystem and/or component (e.g., battery/circuit card) is built by a prime contractor or supplier, both assembly and test processes should be examined in an integrated process flow. At the system level (e.g., missile), components require assembly processes, intermediate test processes, installation, and final acceptance testing. All work breakdown structure levels must be considered to effectively gauge the ability to meet projected cost and schedule targets. The nominal MRL target would be 7.

- If the assessment is being conducted on a pilot production line, emphasis will be placed on understanding what the production capability and capacity is to meet program objectives in cost, schedule (e.g., low rate production rates) and performance and to anticipate whether there will be any problem with full

rate production processes. The nominal MRL target would be 8 as an entrance criterion for Milestone C.

4.3 DETERMINE ASSESSMENT TAXONOMY AND SCHEDULE

The assessment taxonomy encompasses what will be assessed, where the assessments will take place, and who will lead the assessment.

The government program/project office, in conjunction with the prime contractor, should make an early determination of potential issues by breaking out system, subsystem, or component level for analysis and then determining the applicability of components for evaluation. Consideration should also be given to associated test and assembly processes. The following questions have been developed to assist in the determination of *elements* to be assessed. All Critical Technology Elements and other significant areas of the work breakdown structure or bill of materials should be subject to the following filtering questions. Any "yes" responses imply that an assessment of manufacturing readiness may be needed for that element as a function of risk.

Materials: Are there materials which have not been demonstrated in similar products or manufacturing processes?

Cost: Is this item a driver that significantly impacts life-cycle cost (development, unit, or operations and support costs)? Is the technology new with high cost uncertainty?

Design: Is the item design novel or does it contain nonstandard dimensions or tolerances or arrangements?

Manufacturing Process: Will the item require the use of manufacturing technology, processes, inspection, or capabilities that are unproven in the current environment?

Quality: Does the item have historical/anticipated yield or quality issues?

Schedule: Does this item have lead time issues or does it significantly impact schedule?

Facilities: Does this item require a new manufacturing facility or scale up of existing facilities (i.e., new capability or capacity)?

Supply Chain Management: Does the item have anticipated or historical sub-tier supplier problems (e.g., cost, quality, delivery)?

Industrial Base: Does the item have an industrial base footprint with critical shortfalls or is this a critical item manufactured by a sole or foreign source?

It is rarely feasible to visit every supplier of every material, component and assembly to examine the status of their key manufacturing processes. Some elements

should be assessed on-site and others may utilize alternative approaches. The type and depth of the assessment is determined by the risk level of the element. On-site evaluations are typically reserved for the locations where one or more of the following apply:

- The highest percentage of manufacturing cost is incurred
- Final assembly and test is conducted
- The most sensitive manufacturing tasks are accomplished
- The materials, components or subsystems that are the least technologically mature are produced or availability issues exist
- Known significant problems or risks (low yields, high costs, immature manufacturing processes, etc.) exist

Normally, the government program/project office will lead the assessments at the prime contractor(s) and the prime contractor(s) will lead the assessments for its suppliers. Prior to Milestone A, site visits might not be possible since there rarely is any hardware to support the conceptual designs. Under special circumstances, currently running production lines may be visited if it is anticipated that similar process and tooling will be utilized.

The schedule is typically driven by a variety of considerations including timing of acquisition milestone reviews or program baseline reviews; availability of qualified team members; contractor scheduling concerns; etc. For a small technology demonstration project, an assessment might take a single day at one contractor's facility and require a team of two or three persons. Conversely, a major acquisition program may require multiple site visits over a period of months and involve a larger team, not all of whom will go to every site.

4.4 FORM AND ORIENT ASSESSMENT TEAM

Assessments of manufacturing readiness are typically performed by teams and the government program/project office is responsible for forming them. It is a best practice for the government program/project office to lead the team at prime contractors and the prime contractor to lead the team for the sub-tiers. When the prime contractor leads the assessment, it will determine who it wants to include on the team; however, the program/project office should add its own representatives. Team members should be experienced and knowledgeable in the areas of manufacturing engineering, industrial base, quality, supply chain, design, systems engineering, and production to identify potential manufacturing constraints, risks, and the capability of the technology and industrial base to execute the manufacturing efforts. This experience and knowledge is also important for tailoring the reviews to the specific circumstances of the program. Technology or process subject matter experts may be required to identify

issues not expected to be uncovered by general manufacturing, industrial base, quality, and production experts.

Team selection can begin once the scope and a rough schedule of activity is developed. These teams will vary in size depending on the scope of the assessment. Sub teams may be put together to focus on various subsystems or technologies. The team composition will normally lean heavily toward program/project office and service manufacturing subject matter experts. Representatives from DoD staff organizations may participate as well, if the assessment is being performed on an acquisition program approaching a milestone decision.

Strong consideration should be given to including a level of independence for several reasons.

- It adds credibility to the assessment
- It enables alternative views from others who may have a different perspective
- It provides an opportunity to obtain opinions from subject matter experts not normally available to the program
- It promotes a cross-flow of information well beyond the program office

Such a level of independence may be obtained by a variety of means, at the discretion of the service and the program office. Some ideas for achieving independence are as follows:

- Appoint a co-chair independent of the program
- Include subject matter experts independent of the program
- Use an independent technical authority to review the results of the assessment

Team members from outside the program/project being assessed should familiarize themselves with the program/project. They will need to understand the purpose of the assessment, the objectives and status of the program, Critical Technology Elements, critical manufacturing processes, configuration of hardware, and roles and locations of key contractors and suppliers. This can usually be accomplished by reviewing existing briefing materials, contracts, and progress reports and through interaction with program/project personnel.

The program/project office should consider contacting the appropriate office of the Defense Contract Management Agency (DCMA) to gather information on the contractor's current and past performance. DCMA personnel interact with most OEMs frequently and with their key suppliers and may have very useful information about quality problems and other risk areas. Consider including DCMA personnel in on-site evaluation teams if they are available.

It is also important for the program/project office to set expectations for team members early in the process. The following are some of the key areas to be covered:

- Initial schedule
- Format and timing of reporting their results to the team
- Standards of behavior at the contractor's facility
- Security clearances or nondisclosure agreements
- Personal preparation
- The need for a detailed understanding of their assigned area and the role of shop floor observations and off-line discussions with contractor personnel
- Responsibilities after the on-site review

4.5 ORIENT CONTRACTORS BEING ASSESSED

The leader of the assessment (either the government program/project office or the prime contractor) should orient the contractor(s) to be assessed before the assessment occurs. This orientation may involve including contractor personnel in planning meetings as well as providing the contractor with an orientation package that includes:

- The MRL definitions and threads
- Directions to additional materials on http://www.dodmrl.com/
- Self-assessment questions
- An indication of technologies or processes of special interest that should be included in the self assessment

For on-site assessments, the orientation package should also include:

- The questions the assessment team will use
- A strawman agenda for the assessment visit
- Evidence to be provided at the onsite visit (e.g., process maps, proposed manufacturing plan, process capability data, yield data, technology development plans, risk reduction plans, value stream analysis, etc.)
- High-interest areas where shop floor visits and/or discussions with contractor experts will be desired

- Expectations of resources, time, etc. required for the assessment

Make arrangements with the contractor for an assessment team meeting room to be available where private discussions can be held and team members can record their observations. Also, make arrangements with the contractor for assessment team members to bring computers into the facility to facilitate the capture of their observations in electronic format.

4.6 REQUEST CONTRACTORS PERFORM SELF ASSESSMENT

The leader of the assessment should ask the contractor(s) to conduct a self-assessment to address the following basic questions:

- What is the current MRL for each of the key technologies being developed and each key manufacturing process being used?

- If currently funded activities continue as planned, what MRL will be achieved for each key technology or process by the end of this acquisition phase or program? What activities and schedules are required to achieve this MRL?

- In the case of an ATD or ACTD, what MRL would be sufficient for you or an OEM using your technology to commit to it in a product baseline design?

In the case of on-site assessments, the contractor should be prepared to brief the results to the assessment team when it is on-site. For companies that provide key components or subassemblies and for which a site visit is not feasible, the contractor's written self-assessment should be analyzed by the assessment team.

4.7 SET AGENDA FOR SITE VISITS

The leader of the assessment should set the agenda for site visits. Site visits are intended to provide a more detailed understanding than can be gained from briefings and documents. Assessments of manufacturing readiness should be structured in such a way as to take maximum advantage of discussions with contractor experts and first-hand observations of the status of shop floor activities. A balance must be struck between the time spent in briefing rooms and the time spent making observations in the contractor's facility and having discussions with individuals and small groups of the contractor's personnel. A typical agenda for a review may contain the following elements:

1. Contractor welcome, review of agenda, assessment schedule. and orientation to the facility

2. Introduction of assessment team and contractor personnel

3. Briefing to contractor describing objectives and expectations for the on-site visit

4. Contractor overview and discussion of the results of their self-assessment

5. Shop-floor visits to key areas by individuals or small groups

6. One-on-one or small group discussions between assessment team members and contractor subject matter experts focused on key areas

7. Private meeting of assessment team to record and discuss observations

8. Out-briefing by assessment team to contractor

4.8 CONDUCT THE ASSESSMENT OF MANUFACTURING READINESS

4.8.1 REVIEW THE SELF ASSESSMENT

The assessment team should initiate focused dialog at the component, test, and/or assembly process based on complexity, location, personnel availability, etc. In larger assessments, specific technologies, assemblies, subsystems or processes should be assigned to individuals or sub teams.

The MRL threads and the associated definitions represent evaluation criteria for determining manufacturing maturity. The leader of the assessment should review the self assessment and examine targeted components, subsystem and system-level test and assembly processes with respect to the threads. These threads have different applicability at various times during a product development life cycle. The threads can apply at each component, subsystem, system, and eventually at the program level. They should be used to guide examination of various data sources such as process maps, work instructions, and factory tours to assign an MRL to a technology, component, or subsystem.

A series of knowledge-based questions derived from the MRL definitions and threads are typically used to guide the assessment process and determine the MRL of specific elements that are embodied in hardware (e.g. materials, components, assemblies, subsystems).The questions are tailorable to any program and have been incorporated into tools that store the MRL data for the self-assessment. The questions and tools can be found at http://www.dodmrl.com/.

4.8.2 CONDUCT ASSESSMENT

When conducting an assessment of manufacturing readiness, there should be a well-defined hierarchy among the elements assessed. The hierarchy should start at the system level and flow down to the lowest component that forms the smallest unit for examination. The assessment team should determine the MRL threads applicable to each element in the hierarchy and identify the needed system level test and assembly processes that require an MRL assignment. This includes test and assembly steps that would be included in a subsystem or component fabrication. For example, a Printed Wiring Board (PWB) has several assembly and testing steps during the fabrication of

the board. That PWB would be included in a subsystem buildup in an avionics box (i.e., radar) that may require a next higher level assembly and test process.

The threads also serve as a guide or completeness check to alert the assessment team of the need to examine other areas. For example, the self assessment may be for a missile guidance system (as initially determined by the taxonomy in Section 4.3) that was reported to be MRL 3 but targeted to be MRL 4. Additional detail may be needed to discern why it was assessed at MRL 3 and identify the critical steps needed to mature it. Therefore, further assessments may be necessary at the component level as shown in Table 4-1.

Subsystem	Top Level MRL	Observations	Most Critical
Guidance	3	- Lacking detailed process information - Key suppliers identified; need key performance parameters - Need detailed process plans	- Detector from supplier A - Design and production issues - No alternate source
Data Processor	3	- New processor architecture - Immature design tools - New attachment processes needed	- Board supplier can not test at its site - Low yields on initial run
Propulsion	6	- Same as other systems in use - New component scheme	- Revalidate manufacturing process - Supplier handle increased rate
Air Vehicle	7	- Same supplier as system X - Need to test new mating and assembly processes at the prime	- No critical items
Test Plan	6	- Several instances of redesign work and new test processes	- New test strategy and plan - What will new design incorporate? - Manufacturing experience vital

Table 4-1. Example of Added Detail Derived from Site Visits

During the assessment process, a component or subsystem may be found to be more complex than originally thought, so an even more detailed analysis or 'deep dive' may be warranted. If the assessment team determines further examination of critical components is necessary, the MRL threads should be applied at that level. Sub-components are examined along with process steps, and an MRL is determined for this final sub-tier element. Team members should seek existing, objective documentation that supports assessment results in key areas (e.g., plans, yield data, reports, briefings, work instructions).

In determining the manufacturing readiness of a component or subsystem, the key emphasis is on the manufacturing risk. Utilize the MRL Matrix to structure the review and establish target criteria for each thread/sub-thread. If the target criteria are not met, utilize the risk matrix approach in the "DoD Risk Management Guide for Acquisition" to characterize the risks. The team assesses the number and severity of the risks to determine the manufacturing readiness of the component or subsystem.

Finally, the assessment team should include the actions necessary to bring readiness up to the target level in time to transition a technology or support a milestone decision with manageable risk.

4.8.3 COMPLETE THE ASSESSMENT

At the end of each day, DCMA personnel should be asked to provide their perspective and insight on the contractor's presentations and status. If the contractor was unable to provide adequate information to support an assessment in a key area, assign an action item for the contractor to provide the information by a specific date.

Near the end of the assessment, the team should meet at the contractor's facility to discuss its observations and capture its impressions in electronic format. The team should also provide an out-brief to the contractor highlighting strengths and risks, MRL achievements compared to targets, and action items. Finally, the contractors' hospitality and cooperation should be recognized.

MRL assessments are not a simple go/no-go gauge. Therefore, assigning a single MRL to an entire technology or weapon system has little value. Even in a relatively simple case, where an assessment is being accomplished on a single technology with perhaps a half-dozen hardware components, it is *likely* the MRL will vary widely from component to component and perhaps even manufacturing process by manufacturing process for a specific component. Some components may be off-the-shelf, standard hardware, or made with well-established materials and processes from reliable suppliers, thus perhaps having an MRL in the range of 8 to 10. Other components may incorporate new design elements that move well beyond the proven capabilities of a key manufacturing process and perhaps are at MRL 4.

Using a 'weakest link' basis, a technology or system would have to receive an overall MRL that reflects the element of that technology that had the lowest level of readiness, in this case, MRL 4. In many instances, this approach could be misleading and give the impression of an overall level of risk greater than the actual situation. For assessments of more complex subsystems and systems, this simplification becomes even less useful since it is unlikely that every element is going to be, for example, at MRL 6 by Milestone B.

Therefore, the assessment report (as described in section 4.9), should contain a bottom-up assessment of the relative manufacturing readiness at the system, sub-system and component level. Findings for lower level components can be fit into a format for analysis and decision making at higher levels of the program as shown in Table 4-1. Each MRL (at any level) should be identified to provide insight into specific risks.

4.9 PREPARE THE ASSESSMENT REPORT

The results should be documented by team members in a format agreed to in advance. Except in the simplest cases, it may not be feasible for the team to agree on an assessment while on-site at the contractor's facility. Usually some analysis is

required by the assessment team after site visits are complete to clearly define the manufacturing readiness and risk status of the key technologies and manufacturing processes and to put the identified risks into a program context. These final results are then typically documented in a written report or out-brief containing the following:

1. A description of the technology, component, subsystem or system which identifies the elements that were assessed; the key objectives of the development effort; and a discussion of the current state of the art

2. A discussion of the companies which are responsible for the elements that were assessed

3. A list of team members

4. Dates and locations of site visits

5. A description of the manufacturing processes for the elements that were assessed

6. The MRL for each element that was assessed

7. Areas where manufacturing readiness falls short of target MRL
    - Identify key factors
    - Describe driving issues

8. Plans to reach target MRL

9. Assessments of the type and significance of risk to cost, schedule or performance

10. Assessments of the effectiveness of current risk mitigation plans
    - Address right issues?
    - Timely?
    - Adequately funded?
    - Probability of success?
    - Options for increased effectiveness?

The government program/project office is the primary audience for the report since it forms the basis for managing manufacturing risk. In general, the report establishes a manufacturing maturity baseline that should be used to either create a plan to increase manufacturing readiness/maturity sufficiently to support transition to the next phase of acquisition or to demonstrate that the technology is ready for transition.

The report may also provide information to an MDA determination of whether the level of manufacturing risk supports Milestone approval.

When actual MRLs are compared to target values based on the stage of the life cycle, the report provides a basis for an analysis and assessment of the risks associated with each manufacturing thread. Cost, schedule or performance manufacturing risks that are not resolved must be defined and require manufacturing maturity plans. These plans should include a description of the approach to resolve the risk, cost estimates, resources available, and schedule impacts. The manufacturing maturation plan is normally delivered along with the assessment report. See section 5.

5. Manufacturing Maturation Plans and Risk Management

5.1 INTRODUCTION

The purpose of an MRL-based assessment of manufacturing readiness is to analyze current conditions and to identify manufacturing risk in order to assist the program/project manager in creating a plan or options to reduce or remove risks. Identifying risk is a key part of developing risk mitigation efforts; it is a key enabler of program success. Risk management includes risk planning, risk assessment, risk handling and mitigation strategies, and risk monitoring approaches. Thorough assessments of maturity, development of maturation plans, and the use of technology transition plans are fundamental tools for mitigating risk. See the following for further information on risk management:

- DoD Risk Management Guidebook
    - http://www.acq.osd.mil/sse/ed/docs/2006-RM-guide-4Aug06-final-version.pdf
- DoD Risk Management Community of Practice
    - https://acc.dau.mil/RM
- Risk Management Continuous Learning Management Module
    - https://learn.dau.mil/html/clc/Clc1.jsp?cl and select CLM 017.

A key product resulting from an assessment of manufacturing readiness is the MMP, which addresses the manufacturing risk and provides a mitigation plan for each risk area throughout the duration of the program/project, including supplier and sub-tier supplier risk management shortfalls. Every assessment of manufacturing readiness should have an associated MMP for those areas where the MRL has not achieved its target level.

A low MRL assigned to a component is not necessarily bad at an early stage of acquisition. By identifying the risk area(s), necessary investment can be channeled to attain the target MRL by the time of transition to the next phase of the program/project. As a result of risk identification, the program/project can formulate and execute MMPs before the risks become severe. A manufacturing maturity shortfall in an element can be easy or difficult to fix. The following information is needed to decide whether a technology or weapon system is ready to move to the next phase of its life cycle.

- Identification of any elements (technologies, components, assemblies, subsystems, processes, etc.) that have not reached the target MRL

- Understanding of the potential impact if the element fails to mature to the target level as well as how difficult, time consuming, and expensive it will be to bring the element up to an acceptable level of maturity or develop an adequate work around

The remainder of this section describes activities to address risk. The format of the MMP which serves as the manufacturing risk mitigation plan is shown (Section 5.2). Finally, best practices for manufacturing risk mitigation are listed (Section 5.3).

5.2 DEVELOPMENT OF A MANUFACTURING MATURATION PLAN

In conjunction with the contractor, the program/project office should prepare an MMP that covers all manufacturing risk areas. The MMP should be delivered along with the results of the assessment of manufacturing readiness. The following outline for a MMP includes the most essential items in planning for the maturity of a specific element of assessment found to be below its target MRL:

1. Title
2. Statement of the problem
    - Describe the element of assessment and its maturity status
    - Describe how this element of assessment would be used in the system
    - Show areas where manufacturing readiness falls short of target MRL including key factors and driving issues
    - Assess type and significance of risk to cost, schedule or performance
3. Solution options
    - Benefits of using the preferred approach
    - Fall-back options and the consequences of each option
4. Maturation plan with schedule and funding breakout
5. Key activities for the preferred approach
6. Preparations for using an alternative approach
7. The latest time that an alternative approach can be chosen
8. Status of funding to execute the manufacturing plan
9. Specific actions to be taken (what will be done and by whom)
10. Prototypes or test articles to be built

11. Tests to be run

    - Describe how the test environment relates to the manufacturing environment

12. Threshold performance to be met

13. MRL to be achieved and when it will be achieved

5.3 RISK MANAGEMENT BEST PRACTICES

The following best practices are applicable to both acquisition program managers for all programs of record and managers for all technology development projects and demonstrations and pre-systems acquisition programs intending to transition to the TD Phase of acquisition at Milestone A or into a program of record at Milestone B or C. The best practices are categorized into five areas.

1. Recognize the importance of manufacturing and mitigating manufacturing risk to the success of a program/project

    - Accept manufacturing risk management as a basic responsibility, on a par with the management of any other risk

    - Recognize that mitigating manufacturing risk can be the key ingredient of success in transitioning a product or process technology to a program of record

    - Recognize manufacturing risk and readiness as key factors in defining and achieving program/project cost, schedule and performance goals

2. Manage manufacturing risk

    - Incorporate the management of manufacturing readiness, risk, and cost into the basic fabric of managing the program/project

    - Assess, plan, budget, and manage to reach manufacturing maturity and cost targets. For technology development projects, incorporate the target MRL (typically MRL 6) to support the technology transition plan. For programs of record, the target MRLs for CDR, LRIP, and FRP are 7, 8, and 9 respectively

    - Conduct assessments of manufacturing readiness to increase the probability of program success and integrate the results into a broader effort to manage manufacturing risk. These assessments should lead to action-oriented decisions

- Prevent the adoption of a technology by a program of record if it has not reached an appropriate level of manufacturing readiness (normally MRL 6)

3. Monitor the status and progress of manufacturing risk mitigation activities

    - Know the MRL of every technology being considered for application in the program/project

    - Assess and understand manufacturing readiness and risk early in each phase of an acquisition program to establish a baseline

    - Include contractual Statement of Work (SOW) tasking (see Section 6) for the prime contractor and suppliers to support assessments of manufacturing readiness. Also include contractual SOW taskings for best practices that improve producibility, quality, and affordability and enable the assessment of manufacturing maturity

    - Do not rely totally on contractor manufacturing assessments

    - Incorporate manufacturing maturity examination and progress monitoring in management reviews, system engineering technical reviews, and progress reporting

4. Utilize the manufacturing expertise of others to help mitigate manufacturing risk

    - Use the manufacturing expertise available on product center manufacturing staffs and within the service/agency manufacturing technology programs to supplement staff

    - Identify and access trained and experienced manufacturing subject matter experts outside of the service/agency

    - Use the DCMA as a source of information about strengths and weaknesses in a contractor's manufacturing operations

5. Develop program/project office staff skills in identifying and mitigating manufacturing risk

    - Review the manufacturing readiness information and tools available on http://www.dodmrl.com/

    - Support manufacturing training for program/project staff

6. Applying MRLs in Contract Language

6.1 INTRODUCTION

Like all other requirements, MRL-based assessments of manufacturing readiness must be included in contract language to be effective. During the initial stages of acquisition planning and risk identification, a determination should be made of the manufacturing requirements in the planned program. If hardware is being manufactured, the two key drivers in determining the manufacturing requirements are the current phase of acquisition and the overall complexity of the hardware. Once manufacturing requirements are identified, the team can then assess whether manufacturing readiness will be a significant discriminator for the source selection. Discriminators are those key requirements or program risks that separate offerors from each other during the proposal evaluation process. If manufacturing readiness will be a discriminator between offerors, then appropriate language should be incorporated in Section L (Instructions to Offerors) and Section M (Evaluation Criteria) of the Request For Proposal (RFP) so it can be used during the source selection process.

If manufacturing requirements exist, assessments of manufacturing readiness should be included in the Statement of Objectives (SOO) and in the resulting SOW, so they can be a formal part of the contract. Although most of the discussion in this section is oriented towards competitive acquisitions, this recommendation for SOO and SOW language also applies to sole source programs with manufacturing requirements. The acquisition team must determine what MRL will be required at the completion of the phase (e.g., MRL 8 for Milestone C). Once this is determined, the acquisition team can develop requirements, analyze and assess program risks, develop the overall acquisition strategy for the program, and develop the appropriate RFP and contractual language.

This section presents some ideas and strategies for ensuring MRL-based assessments of manufacturing readiness are treated effectively as a part of acquisition activities. It contains methods and examples on how to effectively implement the process for conducting an assessment of manufacturing readiness contractually in a program as part of RFP language (Sections 6.2 and 6.3), SOO language (Section 6.4), and SOW language (Section 6.5). These examples are meant to be tailored to reflect the complexity of the current phase of acquisition.

6.2 STRATEGIES FOR COMPETITIVE RFP LANGUAGE

If manufacturing readiness is a requirement and a source selection discriminator, the RFP should require the offeror's proposal to document the results of an assessment of manufacturing readiness against the MRL definition appropriate for the current phase of the program. The key decision factor should not be the current MRL, but the risk of achieving the final MRL target. Based on the assessment, the offeror's proposal should identify the current MRL and then give an explanation of how the target MRL for each

program element will be achieved by the end of the acquisition phase (e.g., MRL 8 for Milestone C). This information should be used to assess the risk of achieving the target MRL by completion of the proposed phase. The best approach to assess this risk is by assessing the contractors understanding of steps necessary to evaluate their MRL, the steps necessary to achieve the required MRL (e.g., Manufacturing Maturity Plans), and the risk associated with achieving those steps.

Section L of the RFP (Instructions to Offerors) will specify the content and any required format the offeror must submit to substantiate the process to achieve the target MRL. This will reduce the likelihood of misunderstandings between the offeror and government when discussing the program's manufacturing risks and plans.

Example scenario for a program entering the Technology Development Phase: *The RFP will direct required offerors to prepare an overall, initial assessment. The offerors shall have conducted a preliminary assessment of manufacturing readiness using the MRL 4 definitions found in the Manufacturing Readiness Level Deskbook. The results of this assessment shall be discussed in the proposal along with the assessment methodology that the offeror used. The offeror shall provide a Manufacturing Maturity Plan, which will discuss how they will move forward from their assessed MRL to the MRL 6 definition that is expected at the end of the Technology Development Phase. The offeror shall include enough detail for the government to understand all manufacturing risks that are expected and all risk mitigation efforts that will be necessary to achieve the final MRL 6 definition at the end of the phase. The offeror shall discuss how MRL 5 and 6 will be achieved within their plans and schedules.*

6.3 MANUFACTURING READINESS RFP LANGUAGE FOR SOURCE SELECTION

Using assessments of manufacturing readiness in source selection requires language in three key sections of the RFP: Section L (Instructions to Offerors), Section M (Evaluation Criteria), and the SOO. Language should be inserted in Sections L and M only if manufacturing readiness will be a discriminator in the source selection. The SOO language should be included in all RFPs. The RFP content must be consistent among the contract requirement in the SOO (e.g. the requirement to achieve a specific MRL or to conduct periodic assessments of manufacturing readiness during the contract period of performance), Section M (the criteria stating how the evaluation team will evaluate the offeror's proposal to meet or exceed the requirement), and Section L (the instructions for what information must be included in the proposal to allow the evaluators to properly evaluate whether the offeror meets or exceeds the requirement).

Section L sample language:

Sub-factor/Component (TBD)—Manufacturing Readiness Level Demonstration

> The offeror's proposal shall clearly and specifically identify those elements being assessed for manufacturing risk and their current Manufacturing Readiness Levels using the criteria and process identified in the

Manufacturing Readiness Level Deskbook (see http://www.dodmrl.com/MRL_Deskbook_v1.pdf and include the *Manufacturing Readiness Level Deskbook* in the RFP library of referenced documents). The contractor shall describe the approach used to assess the MRLs.

For any MRL that is assessed below MRL 'X', the offeror shall identify the current MRL and provide the supporting rationale for the assessment and a Manufacturing Maturity Plan to achieve the required MRL.

Section M sample language (NOTE—this sample language is written for the situation where a requirement can only be met, and no additional evaluation credit is given for an offer that exceeds the threshold requirement.)

Sub-factor/Component (TBD)—Manufacturing Readiness Level Demonstration

This sub-factor will evaluate the adequacy of the offeror's process and plans to achieve the target MRL as described in the *Manufacturing Readiness Level Deskbook*.

The evaluation color rating of this sub-factor is limited to: Acceptable (Green); Marginal (Yellow); or Unacceptable (Red). The marginal (Yellow) rating is intended to communicate uncertainty and therefore indicate a need for clarification from the offeror, or indicate a need for adjudication by the MDA.

Measure of Merit:

This sub-factor is met (i.e., is acceptable) when the offeror's proposal clearly identifies and substantiates its MRL assessment and has clearly demonstrated that its maturity plan is executable within time and resources allocated to achieve the target MRL by the end of the effort.

6.4 SOO LANGUAGE FOR ALL RFPS

The RFP should specifically describe the respective intentions and roles of the government program office and offeror in preparation, analysis, and reviews of an assessment of manufacturing readiness. For example:

The offeror shall conduct assessments of manufacturing readiness to determine MRLs throughout the life of the contract using the *Manufacturing Readiness Level Deskbook* as a guide. The offeror shall use the process explained in Sections 4.0 and 5.0 of that document as a filter for identifying high manufacturing risk technologies or components and present appropriate risk analysis and associated maturation plans within the Integrated Master Schedule.

The offeror shall specify in a SOW appendix the locations and frequencies of any assessments of manufacturing readiness, along with all the resources to

perform or support these assessments. The offeror shall identify its approach for flowing down these requirements as a function of risk. The offeror shall address how assessments of manufacturing readiness will be executed and monitored to ensure achieving the required level in accordance with their Manufacturing Maturity Plans.

The offeror should assume that the government will lead the assessment of manufacturing readiness at the prime contractor and the prime contractor will lead the assessments at the suppliers with government participation unless clearly specified differently in the proposal. The offeror shall address how MRLs will be monitored to ensure achieving the required level in accordance with their Manufacturing Maturity Plans.

6.5 SOW LANGUAGE FOR CONTRACTS

The contract SOW should include language similar to the following:

The contractor shall conduct assessments of manufacturing readiness using the definitions, criteria, and processes defined in the *Manufacturing Readiness Level Deskbook* as a guide. Assessments will be conducted at the locations and frequencies specified in Appendix TBD. They will be led by the government program office at the prime contractor's facilities. The prime contractor shall lead the assessments at suppliers and include government participants.

The contractor shall develop and implement manufacturing maturation plans or their equivalent for areas in which the MRL is lower than required to meet Milestone X.

The contractor shall monitor and provide status at all program reviews for in-house and supplier MRLs and shall re-assess MRLs in areas for which design, process, source of supply, or facility location changes have occurred that could impact the MRL.

6.6 OTHER DELIVERABLES

Implementation of MRL-based assessments may require some deliverable documentation from the contractor and, if so, should be included in the SOW. Specifically, a plan for implementing MRL-based assessments and any potential MMPs may be deliverable documents. Generally, requirements for official, deliverable data items should be minimized, unless the program office determines it is necessary.

A plan to describe implementation of MRL-based assessment approaches, schedules and responsibilities, etc. may be desired. There are several options for obtaining this plan. Preferably, the contractor's plans for implementing MRLs may be included in a Manufacturing Plan, which may itself be either a deliverable item or not. Alternatively, the SOW may include

an MRL Plan as a formal Contract Data Requirements List (CDRL). Although a Data Item Description (DID) does not exist for an MRL plan, generic DIDs are available, such as for technical reports.

If MMPs are being generated as a result of maturity shortfalls, the program office needs to determine if they need these plans to be deliverable items. Preferably, the MMPs may be documented as part of the program's normal Risk Management process, which should include documented risk mitigation plans, which may or may not be deliverable. Alternatively, MMPs may be included in the SOW as a formal CDRL. Once again there is no dedicated DID for MMPs, but generic technical report DIDs may be acceptable.

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APPENDIX A.
DETAILED MRL DEFINITIONS (THREADS MATRIX)

Table A-1. Manufacturing Readiness Levels for the Technology and Industrial Base Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 (A)	MRL 5	MRL 6 (B)	MRL 7	MRL 8 (C)	MRL 9	MRL 10 (FRP)
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 9	Should be assessed at TRL 9
A – Technology & Industrial Base	A.1 – Industrial base			Potential sources identified to address technology needs. Understand state of the art.	Industrial base capabilities surveyed and known gaps/risks identified for preferred concept, key technologies, components, and/or key processes.	Industrial base assessment initiated to identify potential manufacturing sources. Sole/ single/foreign source vendors have been identified and planning has begun to mini-mize risks.	ICA for MS B has been completed. Industrial capability in place to support manufacturing of development articles. Plans to minimize sole/ foreign sources complete. Need for sole/single/foreign sources justified. Potential alter-native sources identified.	Industrial capa-bility to support production has been analyzed. Sole/single/ foreign sources stability is assessed/moni-tored. Devel-oping potential alternate sources as necessary.	ICA for MS C has been com-pleted. Industrial capability is in place to support LRIP. Sources are available, multi-sourcing where cost-effective or necessary to mitigate risk.	Industrial capability is in place to support start of FRP.	Industrial capability supports FRP and is assessed to support modifi-cations, upgrades, surge and other potential manufac-turing require-ments.

Table A-1. Manufacturing Readiness Levels for the Technology and Industrial Base Thread (continued)

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
A – Technology & Industrial Base	A.2 – Manufacturing Technology Development		New manu-facturing concepts and potential solutions identified.	Manufacturing technology concepts identified through experiments/ models.	Manufacturing Science & Advanced Manufacturing Technology requirements identified.	Required manufacturing technology development efforts initiated, if applicable.	Manufacturing technology efforts continuing. Required manu-facturing tech-nology develop-ment solutions demonstrated in a production-relevant environment.	Manufacturing technology efforts con-tinuing. Required manufacturing technology development solutions demonstrated in a production-representative environment.	Primary manu-facturing technology efforts concluding and some improve-ment efforts continuing. Required manu-facturing technology solutions validated on a pilot line.	Manu-facturing technology process improve-ment efforts initiated for FRP.	Manu-facturing technology continuous process improve-ments ongoing.

Table A-2. Manufacturing Readiness Levels for the Design Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
B – Design	B.1 – Producibility Program	–	–	Relevant materials/pro-cesses evaluated for manufac-turability using experiments/ models.	Initial producibility and manufac-turability assess-ment of preferred systems concepts completed. Results con-sidered in selec-tion of preferred design concepts and reflected in TDS key components/ technologies.	Producibility and manufac-turability assessments of key tech-nologies and components initiated as appropriate. Ongoing design trades consider manufacturing processes and industrial base capability constraints. Manufacturing processes assessed for capability to test and verify in production, and influence on operations & support.	Producibility assessments and producibility trade studies (perform-ance vs. produci-bility) of key tech-nologies/compo-nents completed. Results used to shape Acquisition Strategy, SEP, Manufacturing and Producibility plans, and planning for EMD or technology insertion programs. Preliminary design choices assessed against manufac-turing processes and industrial base capability con-straints. Produci-bility enhancement efforts (e.g., Design for Manufacturing Assembly, Etc. (DFX)) initiated.	Detailed producibility trade studies using knowl-edge of key design charac-teristics and related manu-facturing process capability completed. Producibility enhancement efforts (e.g., DFX) ongoing for optimized integrated system. Manu-facturing processes reassessed as needed for capability to test and verify potential influence on operations & support.	Producibility improve-ments imple-mented on system. Known producibility issues have been resolved and pose no significant risk for LRIP.	Prior produci-bility improvem-ents analyzed for effective-ness during LRIP. Produci-bility issues/ risks dis-covered in LRIP have been miti-gated and pose no significant risk for FRP.	Design produci-bility improve-ments demon-strated in FRP. Pro-cess pro-ducibility improve-ments ongoing. All modifica-tions, upgrades, DMSMS, and other changes assessed for produci-bility.

Table A-2. Manufacturing Readiness Levels for the Design Thread (continued)

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
B – Design	B.2 – Design Maturity	Manufac-turing research opportu-nities identified.	Applications defined. Broad performance goals identi-fied that may drive manu-facturing options.	Top level performance requirements defined. Tradeoffs in design options assessed based on experiments. Product life cycle and technical requirements evaluated.	SEP and T&E Strategy recognize the need for the establishment/ validation of manufacturing capability and management of manufacturing risk for the product life cycle. Draft Key Performance Parameters (KPPs) identified for preferred systems concept. System characteristics and measures to support required capabilities identified. Form, fit, and function constraints identified, and manufacturing capabilities identified for preferred system concepts.	Lower level performance requirements sufficient to proceed to preliminary design. All enabling/critical technologies and compo-nents identified and product life cycle con-sidered. Eval-uation of design KCs initiated. Product data required for prototype component manufacturing released.	System allocated baseline estab-lished. Product requirements and features are well enough defined to support preliminary design review. Product data essential for subsystem/system prototyping has been released. Preliminary design KCs have been identified and mitigation plan in development.	Product design and features are defined well enough to sup-port CDR even though design change traffic may be signifi-cant. All pro-duct data essential for component manufacturing has been released. Potential KC risk issues have been identified and mitigation plan is in place.	Detailed design of product features and inter-faces is complete. All product data essen-tial for sys-tem manufac-turing has been released. Design change traffic does not signifi-cantly impact LRIP. KCs are attain-able based upon pilot line demon-strations.	Major product design features and con-figuration are stable. System design has been vali-dated through operational testing of LRIP items. PCA or equivalent complete as neces-sary. Design change traffic is limited. All KCs are controlled in LRIP to appropri-ate quality levels.	Product design is stable. Design changes are few and gen-erally limited to those required for contin-uous improve-ment or in reaction to obsolesce nce. All KCs are controlled in FRP to appro-priate quality levels.

Table A-3. Manufacturing Readiness Levels for the Cost and Funding Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
C – Cost & Funding	C.1 – Production Cost Knowledge (Cost Modeling)	–	Cost model approach defined.	Initial cost targets and risks identi-fied. High level process chart model developed. Technology cost models developed for new process steps and materials based on experiments.	Manufacturing, material and spe-cial requirement cost drivers identi-fied. Detailed pro-cess chart cost models driven by process variables. Cost driver uncer-tainty quantified.	Prototype com-ponents pro-duced in a production relevant envi-ronment, or simulations drive end-to-end cost models. Cost model includes materials, labor, equipment, tooling/(STE, setup, yield/ scrap/rework, WIP, and capa-bility/capacity constraints).	Cost model updated with design require-ments, material specifications, tolerances, inte-grated master schedule, results of system/subsystem simulations and production relevant prototype demon-strations.	Cost model updated with the results of systems/sub-systems pro-duced in a production-representative environment and with pro-duction plant layout and design and obsolescence solutions.	Cost models updated with results of pilot line build.	FRP cost model updated with result of LRIP build.	Cost model validated against actual FRP cost.

Table A-3. Manufacturing Readiness Levels for the Cost and Funding Thread (continued)

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
C – Cost & Funding	C.2 – Cost Analysis	Identify any manu-facturing cost implica-tions.	Cost elements identified.	Sensitivity analysis conducted to define cost drivers and production development strategy (i.e., lab to pilot to factory).	Producibility cost risks assessed. Initial cost models support AoA and ASR.	Costs analyzed using prototype component actuals to ensure target costs are achievable. Decisions regarding design choices, make/buy, capacity, process capability, sources, quality, KCs, yield/rate, and variability influenced by cost models.	Costs analyzed using prototype system/subsystem actuals to ensure target costs are achievable. Allocate cost targets to sub-systems. Cost reduction and avoidance strate-gies developed. Provide manufacturing cost drivers for “Should-Cost” models.	Manufacturing costs rolled up to system/sub-system level and tracked against targets. Detailed trade studies and engineering change requests supported by cost estimates. Cost reduction and avoidance strategies underway. Update manufacturing cost drivers for “Should-Cost” models.	Costs analyzed using pilot line actuals to ensure target costs are achiev-able. Manu-facturing cost analysis supports proposed changes to require-ments or configura-tion. Cost reduction initiatives ongoing. Update manufac-turing cost drivers for “Should-Cost” models.	LRIP cost goals met and learning curve analyzed with actual data. Cost reduction initiatives ongoing. Touch labor effi-ciency analyzed to meet production rates and elements of ineffi-ciency are identified with plans in place for reduction.	FRP cost goals met. Cost reduction initiatives ongoing.

Table A-3. Manufacturing Readiness Levels for the Cost and Funding Thread (continued)

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
C – Cost & Funding	C.3 – Manufacturing Investment Budget	Potential invest-ments identified.	Program/ projects have reasonable budget esti-mates for reaching MRL 3 through experiment.	Program/ projects have reasonable budget esti-mates for reaching MRL 4 by MS A.	Manufacturing technology initia-tives identified to reduce costs. Program has reasonable budget estimate for reaching MRL 6 by MS B. Estimate includes capital investment for production-relevant equip-ment. All out-standing MRL 4 risk areas under-stood, with approved mitiga-tion plans in place.	Program has updated budget estimate for reaching MRL 6 by MS B. All outstanding MRL 5 risk areas under-stood, with approved mitigation plans in place.	Program has reasonable budget estimate for reaching MRL 8 by MS C. Estimate includes capital investment for production-repre-sentative equip-ment by CDR and pilot line equipment by MS C. All out-standing MRL 6 risk areas under-stood, with approved mitigation plans in place.	Program has updated budget estimate for reaching MRL 8 by MS C. All outstanding MRL 7 risk areas under-stood, with approved miti-gation plans in place.	Program has reasonable budget estimate for reaching MRL 9 by the FRP decision point. Esti-mate includes investment for LRIP and FRP. All out-standing MRL 8 risk areas understood, with approved mitigation plans in place.	Program has reasonable budget estimate for FRP. All out-standing MRL 9 risk areas under-stood, with approved mitigation plans in place.	Production budgets sufficient for pro-duction at required rates and schedule to support funded program.

Table A-4. Manufacturing Readiness Levels for the Materials Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
D – Materials (Raw Materials, Components, Sub-assemblies and Subsystems)	D.1 – Maturity	Material properties identified for research.	Material properties and characteristics predicted.	Material properties validated and assessed for basic manufacturability using experiments.	Projected materials have been produced in a laboratory environment.	Materials have been manufactured or produced in a prototype environment (maybe in a similar application/program). Maturation efforts in place to address new material production risks for technology demonstration.	Material maturity verified through technology demonstration articles. Preliminary material specifications in place and material properties have been adequately characterized.	Material maturity sufficient for pilot line build. Material specifications approved.	Materials proven and validated during EMD as adequate to support LRIP. Material specification stable.	Material is controlled to specification in LRIP. Materials proven and validated as adequate to support FRP.	Material is controlled to specification in FRP.
	D.2 – Availability	–	Material availability assessed.	Material scale-up issues identified.	Projected lead times have been identified for all difficult-to-obtain, difficult-to-process, or hazardous materials. Quantities and lead times estimated.	Availability issues addressed for prototype build. Significant material risks identified for all materials. Planning has begun to address scale-up issues.	Availability issues addressed to meet LRIP needs. Long-lead items identified. Potential obsolescence issues identified.	Long lead procurement initiated for LRIP. Availability issues pose no significant risk for LRIP. Availability issues addressed to meet FRP builds.	Long-lead procurement initiated for LRIP. Availability issues pose no significant risk for LRIP.	Long-lead procurement initiated for FRP. Availability issues pose no significant risk for FRP.	Program is in FRP, with no significant material availability issues.

Table A-4. Manufacturing Readiness Levels for the Materials Thread (continued)

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
D – Materials (Raw Materials, Components, Sub-assemblies and Subsystems)	D.3 – Supply Chain Management	–	–	Initial assess-ment of poten-tial supply chain capa-bility.	Survey completed for potential sup-ply chain sources.	Potential supply chain sources identified and evaluated as able to support prototype build.	Supply chain plans in place (e.g. teaming agree-ments and so forth) supporting an EMD contract award.	Effective supply chain manage-ment process in place. Assess-ment of critical first tier supply chain com-pleted.	Supply chain ade-quate to support LRIP. Assessment of critical second and lower tier supply chain com-pleted.	Supply chain is stable and adequate to support FRP. Long-term agree-ments in place where practical.	Supply chain proven and sup-ports FRP require-ments.
	D.4 – Special Handling (i.e., GFP, Shelf Life, Security, Hazardous Materials, Storage Environment, and So Forth)	–	Initial evalu-ation of potential regulatory requirements and special handling concerns.	List of hazardous materials identified. Special handling procedures applied in the lab. Special handling concerns assessed.	List of hazardous materials updated. Special handling procedures applied in the lab. Special handling requirements identified.	Special hand-ling procedures applied in production-relevant envi-ronment. Special hand-ling requirement gaps identified. New special handling processes demonstrated in lab environ-ment.	Special handling procedures applied in production-relevant envir-onment. Plans to address special handling require-ment gaps complete.	Special handl-ing procedures applied in pro-duction repre-sentative envi-ronment. Special hand-ling procedures developed and annotated on work instruc-tions for pilot line.	Special handling procedures applied in pilot line environ-ment. Special handling procedures demonstra-ted in EMD or technolo-gy insertion programs. Special handling issues pose no signifi-cant risk for LRIP. All work instructions contain spe-cial handling provisions, as required.	Special handling proce-dures applied in LRIP envi-ronment. Special handling proce-dures demon-strated in LRIP. Special handling issues pose no significant risk for FRP.	Special handling proce-dures effectively imple-mented in FRP.

Table A-5. Manufacturing Readiness Levels for the Process Capability and Control Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 (A)	MRL 5	MRL 6	MRL 7	MRL 8 (C)	MRL 9 (FRP)	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
E –Process Capability & Control	E.1 – Modeling & Simulation (Product & Process)	–	Initial models developed, if applicable.	Identification of proposed manufacturing concepts or producibility needs based on high-level process flow-chart models.	Production modeling/simula-tion approaches for process or product are identified.	Initial model/simula-tion (product or process) developed at the component level and used to determine constraints.	Initial model/simulation developed at the subsystem or system level, and used to determine system constraints.	Model/simula-tion used to determine sys-tem constraints and identify improvement opportunities.	Model/sim-ulation verified by pilot line build. Results used to improve process and determine that LRIP require-ments can be met.	Model/ simulation verified by LRIP build, assists in manage-ment of LRIP and determines that FRP require-ments can be met.	Model/ simulation verified by FRP build. Production simulation models used as a tool to assist in manage-ment of FRP.
	E.2 – Manufacturing Process Maturity	–	Identification of material and/or process approaches.	Document high-level manufacturing processes. Critical manu-facturing processes identified through experi-mentation.	Complete a survey to determine the current state of critical processes.	Maturity has been assessed on similar pro-cesses in production. Pro-cess capability requirements have been identified for pilot line, LRIP and FRP.	Manufacturing pro-cesses demon-strated in production-relevant environment. Begin collecting or esti-mating process capability data from prototype build. Process capability requirements refined.	Manufacturing processes demonstrated in a production-representative environment. Continue col-lecting or esti-mating process capability data. Process capability requirements refined.	Manufac-turing processes verified for LRIP on a pilot line. Process capability data from pilot line meets target. Process capability require-ments refined.	Manufac-turing processes are stable, adequately controlled, capable and have achieved program LRIP objectives. Variability experi-ments con-ducted to show FRP impact and potential for continuous improve-ment.	Manufac-turing pro-cesses are stable, adequately controlled, capable, and have achieved program FRP objectives.

Table A-5. Manufacturing Readiness Levels for the Process Capability and Control Thread (continued)

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
E –Process Capability & Control	E.3 – Process Yields and Rates	–	–	Initial esti-mates of yields and rates based on experi-ments or state of the art.	Yield and rates assessment on proposed/similar processes com-plete and applied within AoA.	Target yields and rates estab-lished for pilot line, LRIP, and FRP. Yield and rate issues identified. Improvement plans devel-oped/initiated.	Yields and rates from production-relevant environ-ment evaluated against targets and the results feed improvement plan.	Yields and rates from production-representative environment evaluated against pilot line targets and the results feed improvement plans.	Pilot line targets achieved. Yields and rates required to begin LRIP refined using pilot line results. Improve-ment plans ongoing and updated.	LRIP yield and rate targets achieved. Yields and rates required to begin FRP refined using LRIP results. Yield improve-ments ongoing.	FRP yield and rate targets achieved. Yield improve-ments ongoing.

Table A-6 Manufacturing Readiness Levels for the Quality Management Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
F – Quality Management	F.1 – Quality Management, Including Supplier Quality	–	–	–	Quality strategy identified as part of the TDS and included in SEP.	Quality strategy updated to reflect KC identification activities.	Initial quality plan and quality management system is in place. Quality risks and metrics have been identified and improvement plans initiated. Key Characteristic management approached defined.	Quality data from the production representative environment collected and analyzed and results used to shape improvement plans.	Quality targets assessed against pilot line results feed continuous quality improve-ments. Supplier products have com-pleted qualification testing and first-article inspection. Acceptance testing of supplier products is adequate to begin LRIP. Key Characteris-tics managed.	Quality tar-gets veri-fied on LRIP line. Contin-uous quality improve-ment ongoing. Accept-ance testing of supplier products is adequate to begin FRP. Key Character-istics managed in LRIP.	Quality targets verified on FRP line. Contin-uous quality improve-ment ongoing.

Table A-7. Manufacturing Readiness Levels for the Manufacturing Personnel Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
G – Mfg Workforce (Engineering & Production)	G.1 – Mfg Workforce (Engineering & Production)	–	–	New manufac-turing skills identified.	Manufacturing skill sets identified and production workforce require-ments (technical and operational) evaluated as part of AoA. Availability of process develop-ment workforce for the Technology Development Phase determined.	Skill sets identified and plans devel-oped to meet prototype and production needs. Special skills certifica-tion and training requirements established.	Manufacturing workforce skills available for production in a relevant environ-ment. Identify resources (quan-tities and skill sets) and develop initial plans to achieve requirements for pilot line and production.	Manufacturing workforce resource requirements identified for pilot line. Plans developed to achieve pilot line require-ments. Plans updated to achieve LRIP workforce requirements. Pilot line work-force trained in production representative environment.	Manu-facturing workforce resource require-ments iden-tified for LRIP. Plans developed to achieve LRIP require-ments. Plans updated to achieve FRP workforce require-ments. LRIP personnel trained on pilot line where possible.	LRIP personnel require-ments met. Implement plan to achieve FRP workforce require-ments.	FRP personnel require-ments met. Production workforce skill sets maintained in response to attrition of workforce.

Table A-8. Manufacturing Readiness Levels for the Facilities Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6 B	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
H – Facilities	H.1 – Tooling/STE/SIE	–	–	–	Tooling/STE/SIE requirements are considered as part of AoA.	Identify tooling and STE/SIE requirements and provide supporting rationale and schedule.	Prototype tooling and STE/SIE concepts demonstrated in production relevant environment. Production tooling and STE/SIE requirements developed.	Production tooling and STE/SIE design and develop-ment efforts underway. Manufacturing equipment maintenance strategy developed.	Tooling, test, and inspection equipment proven on pilot line and additional require-ments iden-tified for LRIP. Manufac-turing equipment mainte-nance demon-strated on pilot line.	All tooling, test, and inspection equipment proven in LRIP and require-ments identified for FRP. Manu-facturing equipment mainte-nance schedule demon-strated.	Proven tooling, test, and inspection equipment in place to support maximum FRP. Planned equipment mainte-nance schedule achieved.
	H.2 – Facilities	–	–	Specialized facility require-ments/needs identified.	Availability of manufacturing facilities for prototype devel-opment and pro-duction evaluated as part of AoA.	Manufacturing facilities identi-fied and plans developed to produce pro-totypes.	Manufacturing facilities identified and plans devel-oped to produce pilot line build.	Manufacturing facilities identified and plans devel-oped to pro-duce LRIP build.	Pilot line facilities demon-strated. Manufac-turing facil-ities ade-quate to begin LRIP. Plans in place to support transition to FRP.	Manufac-turing facilities in place and demon-strated in LRIP. Capacity plans ade-quate to support FRP.	Production facilities in place and capacity demon-strated to meet maxi-mum FRP require-ments.

Table A-9. Manufacturing Readiness Levels for the Manufacturing Management Thread

Acquisition Phase		Pre-MSA			MSA	TD		EMD		LRIP	FRP
Technical Reviews		–			ASR	SRR/SFR	PDR	CDR	PRR/ SVR	PCA	–
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4 A	MRL 5	MRL 6	MRL 7	MRL 8 C	MRL 9 FRP	MRL 10
–	Tech-nology Maturity	Should be assessed at TRL 1	Should be assessed at TRL 2	Should be assessed at TRL 3	Should be assessed at TRL 4	Should be assessed at TRL 5	Should be assessed at TRL 6	Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 8	Should be assessed at TRL 9
I – Manufacturing Management	I.1 – Manufacturing Planning & Scheduling	–	–	–	Manufacturing strategy developed and integrated with acquisition strategy. Prototype schedule risk mitigation efforts incorporated into TDS.	Manufacturing strategy refined based upon preferred concept. Prototype schedule risk mitigation efforts initiated.	Initial manufacturing approach developed. All system-design-related manufacturing events included in IMP/ IMS. Manufacturing risk mitigation approach for pilot line or technology insertion programs defined.	Initial manufacturing plan developed. Manufacturing planning included in the IMP/IMS. Manufacturing risks integrated into risk mitigation plans. Develop initial work instructions. Effective production control system in place to support pilot line.	Manufacturing plan updated for LRIP. All key manufacturing risks are identified and assessed with approved mitigation plans in place. Work instructions finalized. Effective production control system in place to support LRIP.	Manufacturing plan updated for FRP. All manufacturing risks tracked and mitigated. Effective production control system in place to support FRP.	All manufacturing risks mitigated.
	I.2 – Materials Planning	–	–	–	Technology development article component list developed with associated lead-time estimates.	Technology development part list maturing. Make/buy evaluations begin and include production considerations reflecting pilot line, LRIP, and FRP needs. Lead times and other risks identified.	Most material decisions complete (make/buy), material risks identified, and mitigation plans developed. BOM initiated.	Make/buy decisions and BOM complete for pilot line build. Material planning systems in place for pilot line build.	Make/buy decisions and BOM complete to support LRIP. Material planning systems proven on pilot line for LRIP build.	Make/buy decisions and BOM complete to support FRP. Material planning systems proven in LRIP and sufficient for FRP.	Material planning systems validated on FRP build.

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APPENDIX B.

ACRONYMS

ACTD	Advanced Concept Technology Demonstration
AoA	Analysis of Alternatives
AS	Acquisition Strategy
ASR	Alternative System Review
ATD	Advanced Technology Demonstration
BOM	Bill of Materials
CDD	Capability Development Document
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CPD	Capability Production Document
DAB	Defense Acquisition Board
DAG	Defense Acquisition Guidebook
DCMA	Defense Contract Management Agency
DFARS	Defense Federal Acquisition Regulation Supplement
DFX	Design for Manufacturing
DID	Data Item Description
DoDI	Department of Defense Instruction
DMSMS	Diminishing Manufacturing Sources and Material Shortages
EMD	Engineering and Manufacturing Development
FRP	Full Rate Production
GAO	Government Accountability Office
ICA	Industrial Capabilities Assessment
IMP	Integrated Master Plan

IMS	Integrated Master Schedule
ITR	Initial Technical Review
JDMTP	Joint Defense Manufacturing Technology Panel
KC	Critical Characteristic
LRIP	Low Rate Initial Production
MDA	Milestone Decision Authority
MMP	Manufacturing Maturation Plan
MRL	Manufacturing Readiness Level
MS	Milestone
MSA	Materiel Solution Analysis
NASA	National Aeronautics and Space Agency
OEM	Original Equipment Manufacturer
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PRR	Production Readiness Review
PWB	Printed Wiring Board
RFP	Request for Proposals
SEP	Systems Engineering Plan
SIE	Special Inspection Equipment
SFR	System Functional Review
SRR	System Requirement Review
SOO	Statement of Objectives
SOW	Statement of Work
STE	Special Test Equipment
SVR	System Verification Review

TD	Technology Development
TDS	Technology Development Strategy
TRA	Technology Readiness Assessment
TRLs	Technology Readiness Level
TRR	Test Readiness Review
WIP	Work in Process