DEPARTMENT OF DEFENSE

Manufacturing Readiness Assessment (MRA) Deskbook

2 May 2009

Prepared by the

Joint Defense Manufacturing Technology Panel (JDMTP)
Version 7.1

This version of the MRA Deskbook will support DoD policy and guidance

DRAFT

CONTENTS

Appendices

Executive Summary

The body of this document is a concise description of suggested best practices, responsibilities, roles, and procedures for applying Manufacturing Readiness Level (MRL) criteria to the Department of Defense acquisition and science and technology communities. The intent is to provide those involved with manufacturing and technology development decisions a greater understanding of how MRLs fit into DoD Acquisition and Science & Technology (S&T); and how Manufacturing Readiness Assessments (MRAs) can serve as an effective tool in assessing manufacturing risk.

The DoD acquisition system is explained in the 5000 series of Regulations and Instructions. This set of documents covers in great detail the “why and how” of acquisition. Basically, it covers how to move a program from one phase to another, what the expectations are for each phase, and explanations of many of the pitfalls and cautions throughout the life of a program. In recent years programs have been experiencing increased cost, schedule, and performance problems both in development and as they enter the later production phase of acquisition to move out to the field and into operational use. MRLs and MRAs were developed to help succinctly identify manufacturing requirements and risks in a building block approach that can start in S&T, build throughout the subsequent acquisition phases and culminate in a program that is ready for production, on cost and schedule, and meets performance requirements.

Matters of manufacturing readiness and producibility are as important to the successful development of a system as those of the readiness and capabilities of the technologies intended for the system design. Their importance has long been recognized in DoD acquisition, but emphasis by both government and industry in recent years has waned. Manufacturing risk management needs renewed emphasis during product realization. Effective use of MRLs and MRAs is seen as a key element of that renewal.

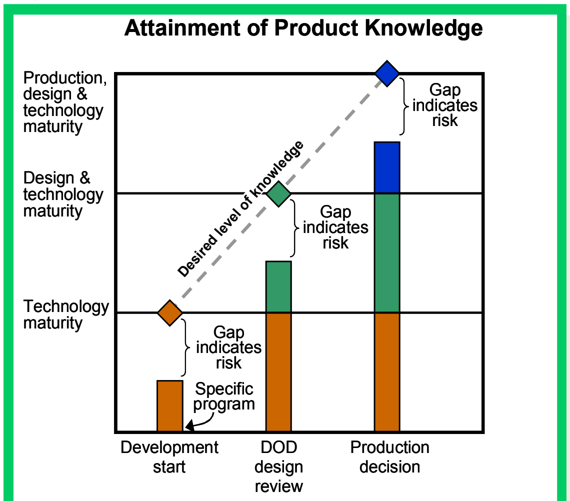
Manufacturing readiness is the ability to harness the manufacturing, production, quality assurance, and industrial functions to achieve an operational capability that satisfies mission needs – in the quantity and quality needed by the warfighter to carry out assigned missions at the “best value” as measured by the warfighter. Best value refers to optimized performance as well as reduced cost for developing, producing, acquiring, and operating systems throughout their life cycle.[1]

Timeliness is also important. Our warfighters must maintain a clear-cut technological advantage over our adversaries. This requires compressed development and acquisition cycles for rapidly advancing technologies. The ability to transition technology smoothly and efficiently from the labs, onto the factory floor, and into the field is a critical enabler for evolutionary acquisition. Manufacturing readiness is vital to success in that transition. Manufacturing readiness properly begins in S&T, continues during the

[1] Definitions in this paragraph are adapted from Deputy Under Secretary of Defense (Science and Technology), *Technology Transition for Affordability: A Guide for S&T Program Managers.* April 2001.

development of systems, and typically persists after a system has been in the field for a number of years.

Various GAO Reports all highlight the widespread schedule and cost problems experienced in DoD weapons programs in recent years.



Source: GAO-05-301 "Defense Acquisitions: Assessments of Selected Major Programs"

- GAO-02-0701 of July 2002 "Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes";
- GAO-03-476 of May 2003 "Assessments of Major Weapons Programs";
- GAO-05-301 of March 2005 "Assessments of Selected Major Weapon Programs";
- and GAO-06-368 of April 2006 "Major Weapon Systems Continue to Experience Cost and Schedule Problems under DoD's Revised Policy"

They cite the lack of knowledge at key decision points (technology, design, and production maturity) as one of the leading causes of these problems and show numerous specific examples. The GAO strongly recommends broader use of knowledge-based decision making using specific criteria at key decision points as a solution.

The introduction of Technology Readiness Levels (TRLs) over the last decade provided an accepted common language and measurement scale intended to strengthen communication within and between the DoD S&T and acquisition communities, both in government and industry. Stakeholders in all parts of the acquisition system now expect that a Critical Technology Element (CTE) will have an appropriate TRL, or level of maturity, prior to acceptance as a baseline technology for a weapon system. They also embrace the concept that technology should have only an acceptable level of risk in order to pass through each acquisition milestone decision point and that TRLs are a way of measuring and communicating that risk.

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

The MRA Deskbook introduces MRLs as an accepted way to describe manufacturing maturity and suggests activities, such as conducting MRAs, which could be carried out by Acquisition Program Managers (PMs), S&T Program Managers, and DoD Acquisition Executives.

The body of this deskbook includes the following:

- A description of the MRLs (Section 2)
- A description of MRA activities appropriate for each phase of the acquisition life cycle (Section 3)
- A description of the MRA process, results, analysis and reporting (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/MRAs (Section 6)
- Appendices with additional information and descriptions of ideas and concepts presented throughout this deskbook

The expectation is that the basic MRA process will remain relatively stable over time, whereas the details implementing the process will evolve and become more or less explicit over time. As these changes occur and as DoD policy for manufacturing readiness evolves, the deskbook will be periodically updated.

Section 1: Introduction

1.1 BACKGROUND

Manufacturing Readiness Level (MRL) definitions were developed by a joint DoD/industry working group under the sponsorship of the Joint Defense Manufacturing Technology Panel (JDMTP). The intent was to create a measurement scale that would serve the same purpose for manufacturing readiness as Technology Readiness Levels serve for technology readiness – to provide a common metric and vocabulary for assessing and discussing manufacturing maturity, risk and readiness. MRLs were designed with a numbering system to be roughly congruent with comparable levels of TRLs for synergy and ease of understanding and use.

A Manufacturing Readiness Assessment (MRA), for the purposes of this document, is a structured evaluation of a technology, component, manufacturing process, weapon system or subsystem using the MRL definitions as a standard. It is performed to:

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

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.). These reviews, while often highly structured and well managed, did not use a uniform metric scale to measure and communicate manufacturing risk and readiness. They were not conducted on S&T efforts or in early acquisition phases. Furthermore, the rigor and frequency of these types of reviews has declined sharply over the last 15 years. The manufacturing knowledge, skills and capability of the acquisition workforce has declined in parallel with declining management emphasis on manufacturing risk management. The subject of manufacturing risk management has virtually disappeared from DoD and service acquisition guidance documents. Yet the accompanying impacts to cost, schedule and performance have grown.

Studies by the General Accountability Office show the nation has paid a high price for allowing this capability to erode. In a 2005 report of 26 problem programs valued at $627B, each had an average cost growth of 37% and an average schedule slip of 16.7%. Their reports 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. The introduction of MRLs and MRAs addresses this lack of knowledge. It forms the basis for rebuilding the ability to manage manufacturing risk in acquisition while increasing the effectiveness of the Science and Technology programs in transitioning new technology to weapon system applications. This ability is a critical measure of success and customer satisfaction.

Senior DoD S&T management embraces the principle that, for hardware intensive programs, manufacturing readiness is key to timely and affordable transition of technology into weapons programs. Acquisition programs increasingly expect that technologies will be “mature” before accepting them for transition – mature in both the technology readiness and manufacturing readiness dimensions. Manufacturing readiness assessment and maturation plans using MRLs are becoming a standard requirement for transition planning of Advanced Technology Demonstration (ATD) programs and other high-visibility technology efforts within the DoD. Managers are now responsible for establishing and managing both the performance maturity and the manufacturing maturity of their technologies.

A number of major DoD weapon system suppliers and Original Equipment Manufacturers (OEMs) have integrated MRLs into their assessment of technologies to be incorporated into product designs. 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. S&T managers that work with prime contractors and OEMs to foster the achievement of manufacturing maturity for their technology will have an advantage over those managers that are not.

Section 2: Manufacturing Readiness Levels

2.1 INTRODUCTION

This section provides the definitions of Manufacturing Readiness Levels and examines their relationship to Technology Readiness Levels.

The basic goal of all acquisition programs is to put advanced capability in the field in a timely manner with acceptable affordability and supportability. Some key risks in doing this are beyond the program manager's control (e.g. changing mission requirements, external budget changes, etc.). Two key risk areas that can and must be managed effectively by program managers are immature product technologies and/or immature manufacturing capability. The ability to measure these risks is fundamental to managing them and suitable measurement scales are now in place for both.

Manufacturing readiness measures in combination with technology readiness measures can be very effective in helping acquisition manager's deal with the risks associated with developing and fielding advanced weapon systems. Solid assessments of maturity, development of maturation plans, and the use of technology transition plans are fundamental tools for mitigating risk. These measures can be used as a foundation which will ultimately aid in improvements in cost, schedule and performance.

Manufacturing measures are also vital to success for managers of Joint/Advanced Concept Technology Demonstrations (JCTDs/ACTDs) and Advanced Technology Demonstrations (ATDs). The vision of DoD leadership is for S&T managers to embrace the need to mature manufacturing capability as a fundamental responsibility in preparing for technology transition. Managers are expected to assess manufacturing readiness using MRLs early in their programs to establish a baseline, and then use the results to create a manufacturing maturation plan to reach suitable manufacturing readiness goals agreed to by their transition customers. The goals are to be embodied in Technology Transition Agreements or Plans to manage the transition process from a manufacturability and producibility standpoint. These actions are important to S&T managers because, in so doing, they are able to achieve and convincingly demonstrate a level of readiness for technology transition that their transition customers will find credible. This will greatly increase the probability of technology insertion – the ultimate goal of an S&T investment.

2.2 MRLs AND TRLs

Manufacturing readiness and technology readiness go hand-in-hand. It is quite common for manufacturing readiness to be paced by technology readiness or design stability. Manufacturing processes will not be able to mature if the product technology or product design is not stable. For that reason, the MRL definitions were designed to include a nominal level of technology readiness as a requisite for each level of manufacturing readiness.

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 NASA and is the preferred technology maturity measurement approach for all new DoD programs. TRLs have been primarily used as a tool to assist in the tracking of technologies in development and their transition into production. The nine 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

Primary approaches to the implementation of MRLs for new technologies are found in the DoD Technology Readiness Assessment Deskbook. This DoD Manufacturing Readiness Assessment Deskbook provides greater detail and guidance on the application of MRLs for acquisition system managers as well as S&T managers. MRLs, in conjunction with TRLs, are key measures that define risk as a technology or process is matured and transitioned to a system. MRLs can also be used to define manufacturing readiness and risks at the weapon system or subsystem level.

2.3 BASIC MANUFACTURING READINESS LEVEL DEFINITIONS

MRLs operate within the Integrated Defense Acquisition, Technology, and Logistics Lifecycle Management Framework. There are ten MRLs (numbered 1 through 10) which are correlated to the nine Technology Readiness Levels in use (Appendix A). The final level (MRL10) measures aspects of lean and continuous improvement for systems in production.

MRL 1: Manufacturing Feasibility Assessed

This is the lowest level of manufacturing readiness. The focus is on a top level assessment of feasibility and manufacturing shortfalls. Basic manufacturing principles are defined and observed. Begin basic research in the form of studies (i.e. 6.1 funds) to identify producibility and materiel solutions.

MRL 2: Manufacturing Concepts Defined

This level is characterized by developing new manufacturing approaches or capabilities. Applied Research translates basic research into solutions for broadly defined military needs. Begin demonstrating the feasibility of producing a prototype product/component with very little support/data available. Typically this level of readiness is associated with Applied Research (i.e. 6.2 funds) in the S&T environment and includes identification and study of material and process approaches, including modeling and simulation.

MRL 3: Manufacturing Concepts Developed

This begins the first real demonstrations of the manufacturing concepts. This level of readiness is typical of technologies in the S&T funding categories of 6.2 and 6.3. Within these levels, identification of current manufacturing concepts or producibility has occurred and is based on laboratory studies. Materials have been characterized for manufacturability and availability but further evaluation and demonstration is required. Models have been developed in a lab environment that may possess limited functionality.

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

This level of readiness is typical for S&T Programs in the 6.2 and 6.3 Advanced Development categories, and acts as an exit criteria for the Materiel solution Analysis (MSA) phase approaching a Milestone (MS) 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 manufacturing risks have been identified for prototype build. Manufacturing cost drivers have also been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special needs for tooling, facilities, material handling and skills.

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 midpoint of an ATD program. 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 which is based upon a detailed end-to-end value stream map.

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

This MRL is associated with readiness for a MS B decision to initiate an acquisition program by entering into the Engineering & 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 completion of S&T development and acceptance into a baseline 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. However, preliminary design of critical components has been completed so that producibility assessments of key technologies can be complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment. A detailed cost analysis should include design trades and allocated cost targets. Producibility considerations have shaped system development plans. Industrial Capabilities Assessment (ICA) for MS B has been completed and long lead and key supply chain elements are 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 & Manufacturing Development (EMD) Phase leading to the Post-CDR Assessment. Technologies should be maturing to at least TRL 7. System detailed design activity is underway. 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 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. Supply chain and supplier quality assurance (QA) elements have been assessed and long lead procurement plans are in place. 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 MS C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is essentially complete and sufficiently stable to enter low rate production. All materials are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment. Processes are under control such that any known producibility risks pose no significant risk for low rate production. There is an Engineering Cost Model driven by the stable detailed design and this cost model has been validated. The Industrial Capability Assessment for MS C has been completed and shows that the supply chain is established and stable.

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

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 at least TRL 8. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). During LRIP all systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing processes and procedures are established and controlled in a low rate production environment to three-sigma or some other appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, with learning curves validated. 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

The system, component or item is in full rate production. Technologies should have matured to at least 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. All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. 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.

2.4 DETAILED MRL THREAD DEFINITIONS

Successful manufacturing has many dimensions. MRL threads have been defined that organize these dimensions into subject areas for ease of understanding. This enables a more detailed understanding of manufacturing readiness and ensures continuity in maturing manufacturing from one level to the next more. A criterion matrix is shown in Appendix B, providing a detailed set of MRL definitions organized into the following nine threads:

- **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.

- **Materials:** Requires an analysis of the risks associated with materials (including basic/raw materials, components, semi-finished parts, and subassemblies).

- **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.

- **Process Capability and Control:** Requires an analysis of the risks that the manufacturing processes may not be 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 Personnel:** Requires an assessment of the required skills and availability in required numbers 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).

The matrix allows a user to separately trace and understand the maturation progress of each of the nine threads as readiness levels increase from MRL 1 though MRL 10.

Section 3: MRLs and the Acquisition Life Cycle Framework

3.1. INTRODUCTION

DoDI 5000.02 requires manufacturing feasibility at MS A and prototype manufacturing capability at MS B, but does not place significant emphasis on manufacturing risk reduction until the Engineering & Manufacturing Development (EMD) Phase of acquisition. DoD leadership has recognized that program success depends on manufacturing risk management being active in S&T and every phase of acquisition from early materiel solution evaluations through production. Manufacturing risk management must also be an integral element in the development of all hardware-intensive weapon system technologies if timely and cost-effective transition of that technology is to occur. The identification and assessment of manufacturing risk will be accomplished using the appropriate MRL associated with the program's life cycle phase. This will highlight areas needing management attention and help to ensure successful execution and transition of the program into the next phase. These risk areas will be identified at each Milestone Decision along with a Manufacturing Maturation Plan (MMP) to ensure that the next phase will achieve the appropriate MRL at the next decision point.

Figure 3.1 below indicates the nominal relationship between specific MRLs and the Acquisition Life Cycle Framework as well as the nominal relationship of MRLs to TRLs.

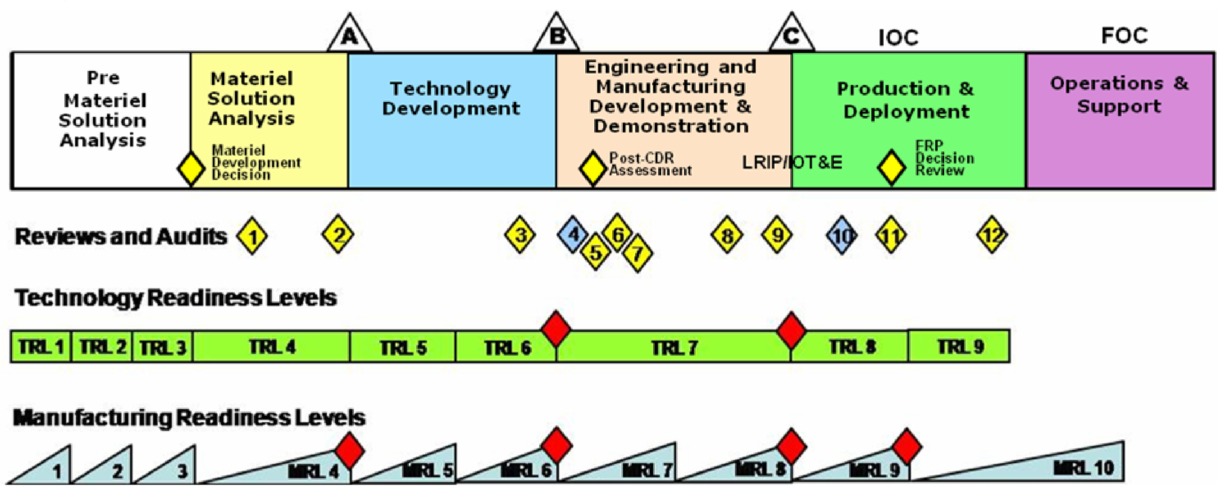


Figure 3.1. Relationship of MRLs to system milestones and TRLs.

3.2 MANUFACTURING READINESS IN THE S&T ENVIRONMENT

Successful technology transition to a weapon system application is the ultimate goal for the DoD S&T program. Program managers must be mindful that the environment for technology transition is changing rapidly. The evolutionary acquisition approach that has been adopted as a standard for DoD requires acquisition program managers to incorporate only mature (manageable-risk) technologies in each iteration. Thus, the acquisition community expects that labs will provide technology mature enough to transition smoothly (meet cost, schedule and performance requirements) into product designs as weapon system development begins prior to or shortly after the start of the Engineering & Manufacturing Development (EMD) phase of acquisition. In the current era of performance-based specifications and increased control of configuration by prime contractors and other OEMs, industry is making technology transition decisions even more frequently than in the past. Most prime contractors and OEMs do not make one-dimensional decisions about which technologies to use in their designs. Contractors should consider not only performance risk, but also risk associated with cost, schedule, and manufacturing process capability, as well as availability of materials and components. Increasingly, prime contractors and OEMs are integrating their own forms of MRLs into their gated technology transition processes to help decide when a technology is mature enough to use in a product design.

For all S&T program managers, consideration of manufacturing risks and issues should begin early in technology development and intensify as the technology matures so that manufacturing maturity is sufficient at the time of transition to support rapid and affordable weapon system incorporation. All hardware intensive S&T programs with defined transition paths to acquisition programs should have an MRA performed before transition occurs. All identified risks will include an approved MMP from the acquisition program office that will incorporate this technology into their program. See Appendices A and B, which show MRL definitions and threads.

MRLs 1-2 serve to highlight manufacturing issues requiring attention prior to the Materiel Solution Analysis Phase. Manufacturing issues during Basic Research (6.1) are generally focused at identifying new materials and/or manufacturing processes. During Applied Research (6.2) these newly required materials and processes become better defined.

MRLs 3-6 each have detailed definitions that are designed to be appropriate for technologies at the corresponding TRL levels. Generally these are late S&T programs or early acquisition programs. These S&T programs include ATDs with 6.3 or 6.4 funding and Manufacturing Technology programs with 6.3 or 7.8 funding. Some elements of the MRL definitions apply directly to S&T programs, but many are more suitable for assessing the readiness of weapon systems.

MRLs 7-10 are not as relevant for S&T efforts because it would be very unusual for an S&T effort to be expected to fund efforts to reach these higher levels of readiness since MRL 6 is normally considered sufficient to support technology transition. Some hardware elements of an S&T technology may consist of off-the-shelf elements (resistors, sheet metal, etc) that carry little manufacturing risk and may have a maturity level above MRL 6 and thus require little attention.

3.2.1 Best practices for ATD programs and Manufacturing Technology programs

- Plan and budget the program with the understanding that the program should achieve a target MRL along with the target TRL to be ready to transition.
- Perform a baseline Manufacturing Readiness Assessment early in the program to establish a starting Manufacturing Readiness Level and include the transition customer in this process.
- Work with transition customers to identify the target MRL that will be acceptable for transition (usually MRL 6) and include this information in the Technology Transition Agreement.
- 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. Intermediate MRAs may be required. Identify adequate funding and manage the execution of the plan.
- Perform a final MRA to confirm that the target MRL has been reached and include the transition customer in this process.

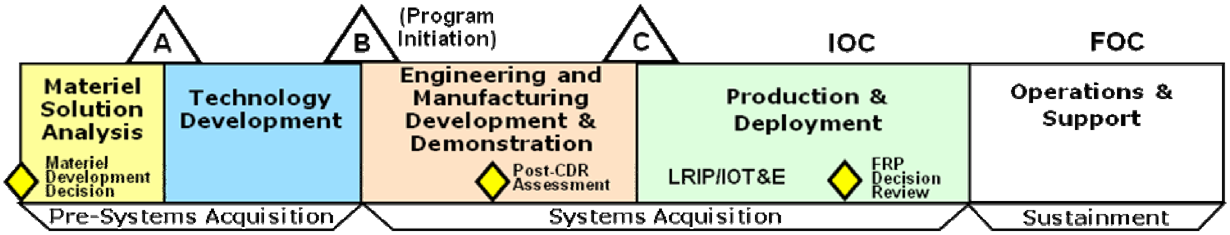
3.3 MANUFACTURING READINESS IN THE ACQUISITION ENVIRONMENT

3.3.1 PRE-MATERIEL DEVELOPMENT DECISION

The capability of the industrial base to provide the vital components and materials should be a fundamental consideration even in the earliest phases of the acquisition cycle. Just as system concepts often imply a range of technology solutions, they may also imply a range of materials and components, some of which may be well beyond the current capability of the industrial base. An awareness of these risks is critical to an intelligent concept selection. The analysis of competing system concepts and their related technology needs that takes place during this period must address the manufacturing dimension, weighing the implied manufacturing risks and cost impacts.

According to DoDI 5000.02, the Analysis of Alternatives (AoA), prepared for entry into the Materiel Solution Analysis Phase, "shall assess the critical technology elements (CTEs) associated with each proposed materiel solution, including technology maturity, integration risk, manufacturing feasibility, and, where necessary, technology maturation and demonstration needs." To be effective, the AoA must include robust provisions for examining the manufacturing feasibility and cost implications of the various technology choices being examined.

3.3.2 MATERIEL SOLUTION ANALYSIS (MSA) PHASE



The purpose of this phase is to refine the initial concept chosen and develop a Technology Development Strategy (TDS) that will guide the execution of the Technology Development Phase.

DoDI 5000.02 requires that the TDS documents the following:

- The rationale for adopting an evolutionary strategy or a single-step-to-full-capability strategy.
- How the program will be divided into development increments, if applicable.
- A limitation on how many prototypes are to be produced during this phase.
- A program strategy that includes overall cost, schedule and performance goals for the total R&D program.
- Specific cost, schedule and performance goals, including exit criteria for the first technology spiral demonstration.
- A test plan to assure that goals and exit criteria are met.

DoDI 5000.02 does not make specific mention of manufacturing considerations for the Materiel Solution Analysis Phase, but it is implied, as failure to address manufacturing risk in the development of the Technology Development Strategy can be a costly mistake which can be very difficult to recover from in later program phases.

3.3.2.1 Best practices associated with the Materiel Solution Analysis Phase include:

- Manufacturing subject matter experts are engaged in the Analysis of Alternatives (AoA) activity and the development of the TDS.
- Knowledge of manufacturing maturity and risk influence the definition of development increments.

- The most feasible and representative materials, manufacturing processes and facilities are used to produce prototypes.

The plan resulting from the AoA is executed during Materiel Solution Analysis and the system concept should become better defined as the phase progresses. The system definition should be further shaped by knowledge of the manufacturing maturity and risk of the various technologies under consideration as well as their associated performance maturity.

During the early Materiel Solution Analysis Phase the manufacturing maturity will be determined by evaluating the AoA against MRL 3 criteria to identify risk in the following areas;

- Adequacy of manufacturing sources understood.
- Basic manufacturing concepts identified and understood.
- Basic material producibility and manufacturability defined.
- Unique and critical manufacturing processes identified.
- Areas currently beyond manufacturing state of art identified.

The above will be addressed through an initial MRA within one year upon starting this phase. There will be a final MRA performed prior to MS A in sufficient time to allow an MRA MS A final report to be provided to appropriate Milestone Decision Authority 60 days before the MS A decision occurs. This MRA will be assessed using MRL 4 criteria to determine that all manufacturing risks have been assessed at the appropriate level and that an appropriate Manufacturing Maturity Plan is in place to transition into Technology Development Phase. The MRA must address the following areas;

- Industrial Base/Supplier risks are identified.
- Manufacturability risks are identified.
- A Manufacturing/Quality strategy addressing risk is in place and incorporated in the TDS.

Two Systems Engineering reviews, the Alternate Systems Review and the Initial Technical Review, are normally conducted during the Materiel Solution Analysis Phase. Manufacturing subject matter experts should be included in these activities and a number of manufacturing-related readiness criteria should be addressed during these reviews. The readiness criteria are detailed in Appendix C.

3.3.3 TECHNOLOGY DEVELOPMENT (TD) PHASE

The MS A decision point marks the entry into the Technology Development Phase of acquisition. The purpose of this phase is to reduce technology risk and to determine the appropriate set of technologies to be integrated into a full system. This includes product technologies and manufacturing capabilities. 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.

As part of the TDS, the results of the MRA performed during the Materiel Solution Analysis Phase will be used as a baseline reference for this activity. If an MRA has not been performed prior to MS A, a baseline MRA should be performed early in Technology Development to identify a baseline level of manufacturing maturity for the technology under development and, at a minimum, all non-software Critical Technology Elements (CTEs). This review will be performed by a manufacturing team selected by the program manager and may possibly include manufacturing subject matter experts and other objective reviewers as required. The timing and scope of the review should be coordinated with the appropriate decision authority.

The MRA report during the Technology Development phase should:

- Describe the technology or hardware and the rationale for designating it as a CTE or manufacturing risk area.
- Identify the companies and facilities that could likely manufacture the items incorporating the technology.
- Describe how well the technology or hardware conforms to MRL 4 requirements for each MRL thread and discuss the basis for the assessment.
- Highlight any areas where a technology or hardware falls short of MRL 4 requirements; discuss the risks that these shortfalls pose to the program.

Initial risk should have been established in the Materiel Solution Analysis Phase and may be further refined during the Technology Development phase as technology alternatives are identified and manufacturing processes mature. The MRA results should be used to form the basis of detailed plans for maturing the manufacturing aspects of the MMP for the system and bringing them to at least MRL 6 prior to the end of the Technology Development Phase. These MMPs can be incorporated into the program TDS. Technologies identified to have a maturity level less than MRL 4 at the start of this phase will require special attention for maturation and risk mitigation in order to bring them to MRL 6 at MS B.

Knowledge of the manufacturing maturity and risk for all technology under development, including all non-software CTEs, is a vital part of the decision process at MS B. A formal MRA should be performed near the end of this phase to prepare for the MS B decision. The timing of the review should be such that the results will be available to the DoD decision makers at least 60 days prior to the scheduled MS B decision point. As in the earlier review, the team for this evaluation should be selected by the Program Manager, and when necessary, may include manufacturing subject matter experts and other objective reviewers as required. These objective reviewers may include service representatives or manufacturing subject matter experts from other organizations such as service or product division staffs.

For each evaluated area, the resulting MRA report should:

- Describe the technology and hardware and the rationale for designating it as a risk area.
- Identify the capability of the industrial base to support the development and eventual production. This could involve the identification of potential companies and facilities that will likely manufacture the items incorporating the technology.
- Describe how well the appropriate threads conform to MRL 6 requirements and discuss the basis for the assessment.
- Highlight any areas where a risk area falls short of MRL 6 requirements; discuss the risks that these shortfalls pose to the program, and discuss the status of efforts to mitigate those risks.

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

a. Request a delay in the MS B decision point to allow time to mature the technology.

b. Select alternative, more mature technologies.

c. Carry immature technologies (and higher levels of risk) into the MS B review and submit a Manufacturing Maturation Plan. The plan should include funding requirements.

A Technology Readiness Assessment is normally performed in the same timeframe prior to MS B. This TRA should be closely coordinated with the MRA. Manufacturing subject matter experts should participate in this TRA and any others that are performed.

Four major systems engineering reviews are normally conducted during this phase:

- System Requirement Review (SRR)

- System Functional Review (SFR)
- Technology Readiness Review
- Preliminary Design Review (PDR)

Manufacturing subject matter experts should be included in these activities and a number of manufacturing-related readiness criteria should be addressed. The readiness criteria are detailed in Appendix C.

Information gathered through participation in PDR, TRA and SRR activities can contribute supporting information to an MRA.

According to DoDI 5000.02, a project exits the Technology Development Phase when "an affordable program or increment of militarily useful capability has been identified; the technology and manufacturing processes for that program or increment have been assessed and demonstrated in a relevant environment; manufacturing risks have been identified; and a system or increment can be developed for production within a short timeframe (normally less than 5 years for weapon systems)."

3.3.4 Engineering & Manufacturing Development (EMD) PHASE

MS B determines if a new acquisition program will be launched and marks the entry point into the EMD Phase. This phase was formerly called the System Design & Development Phase. In the name change, much of the former emphasis on manufacturing risk management that used to take place during this phase has been lost. DoDI 5000.02 defines the purpose of EMD as*: " to develop a system or an increment of capability; complete full system integration; develop an affordable and executable manufacturing process; ensure operational supportability with particular attention to minimizing the logistics footprint; implement human systems integration (HSI); design for producibility; ensure affordability; protect CPI by implementing appropriate techniques such as anti-tamper; and demonstrate system integration,interoperability, safety, and utility."*

According to 5000.02, "*EMD has two major efforts: Integrated System Design, and System Capability and Manufacturing Process Demonstration. …This effort shall end when the system meets approved requirements and is demonstrated in its intended environment using the selected production-representative article; manufacturing processes have been effectively demonstrated in a pilot line environment; industrial capabilities are reasonably available; and the system meets or exceeds exit criteria and Milestone C entrance requirements."* Significantly, DODI 5000.02 list having "no significant manufacturing risks" among the entry criteria into MS C.

From a manufacturing perspective, the purpose of EMD phase is to ready the acquisition program for production. 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 MRL 8 prior to the decision point for entry into production (MS C). The program must focus on program-wide manufacturing risks such as assembly, integration and test operations; the performance of the program supply chain; 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. These risk reduction activities should be reflected in the acquisition strategy that guides activity during EMD. The MRL 8 target should also be reflected in the acquisition program baseline. DoDI 5000.02 requires that each program or increment shall establish program goals-thresholds and objectives-for the minimum number of cost, schedule, and performance parameters that describe the program over its life cycle.

Prototype articles manufactured during EMD should be made in an environment as representative of production as is practical – using production-representative materials, components, tooling, facilities and personnel.

Tracking and managing progress toward MRLs 7 and 8 should be a significant part of program management activity during EMD if the MS C decision will lead to Low Rate Initial Production (LRIP). If the MS C decision is for Full Rate Production (FRP), the MRL target should be MRL 9. Manufacturing risk management and progress toward MRL 8/9 should be a normal part of program reviews. The results of the final MRA performed during the Technology Development Phase will be used as a baseline reference for this activity. If the program has entered the acquisition cycle at MS B, a baseline MRA should be performed early in EMD.

A number of systems engineering reviews are normally conducted during EMD. Manufacturing subject matter experts should be included in these reviews and a number of manufacturing readiness criteria should be addressed as outlined in Appendix C.

The key system engineering reviews that are normally conducted during EMD are:

- Preliminary Design Review (If not conducted during TD)
- Critical Design Review
- Test Readiness Review
- System Verification Review (Functional Configuration Audit)
- Technology Readiness Review
- Production Readiness Review

To be fully effective each of these reviews should emphasize some specific manufacturing-oriented criteria as described in Appendix C. Manufacturing subject matter experts should be included in the teams that conduct these reviews.

Production Readiness Reviews (PRRs) have traditionally covered many of the threads included in the MRLs. However, they have not been organized to assess manufacturing maturity in the same structured format as the MRA. To meet the requirement for an MRA, PRR plans should address MRL threads and critical technologies with prime contractors and key suppliers.

A PRR/MRA will be performed during the latter part of EMD to assess a program's readiness to enter into Low Rate Initial Production. The team will be selected by the Program Manager and will normally have a core group of program office manufacturing subject matter experts and may include other objective representatives if required. The timing of the PRR/MRA will be coordinated with the Milestone Decision Authority and will normally be planned so as to have a report of PRR/MRA results to the appropriate reviewers not later than 60 days prior to the MS C decision point. Depending on the size and scope of the program, the PRR/MRA may be performed in increments during EMD and may involve site visits to the facilities of a number of key suppliers of subsystems and components.

The resulting PRR/MRA report should include the following:

1. For each evaluation area (Critical Technology Element, process, component, assembly, subsystem, etc.), describe the technology, the hardware that will require the technology and the rationale.

2. For each appropriate element, identify the capability of companies and facilities to manufacture items that require the technology.

3. Describe how well each appropriate element conforms to MRL 8/9 requirements for each MRL thread and discuss the basis for the assessment.

4. Discuss how overall program preparations compare to MRL 8/9 criteria for each MRL thread.

5. 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.

6. Estimate the schedule or funding changes required to correct any significant shortfalls.

If any CTEs or 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:

a. Request a delay in the MS C decision point to allow time to mature the technology and/or manufacturing process.

b. Select alternative, more mature technologies and/or manufacturing processes.

c. Carry immature technologies or program-level manufacturing preparations (higher levels of risk) into the MS C review and submit a MMP along with the results of the PRR/MRA.

3.3.5 PRODUCTION AND DEPLOYMENT PHASE (LRIP/FRP)

At MS C the decision is made as to whether the program will proceed into the Production and Deployment Phase. DoDI 5000.02 states:

> *"The purpose of the Production and Deployment Phase is to achieve an operational capability that satisfies mission needs. Operational test and evaluation shall determine the effectiveness and suitability of the system. The MDA shall make the decision to commit the Department of Defense to production at Milestone C and shall document the decision in an ADM. Milestone C authorizes entry into LRIP (for MDAPs and major systems), into production or procurement …. or into limited deployment.."*

Programs may be structured with either one or two major decision points for this phase. The MDA for MS C will decide if they will enter Full Rate Production. For some larger programs, the MS C decision may allow the program to enter Low Rate Initial Production and establish a later FRP decision point. Among other entry criteria, DoDI 5000.02 requires that systems entering this phase have *"no significant manufacturing risk"* and further requires that systems entering full rate production *"have manufacturing processes under control."* For programs entering LRIP, achieving MRL 8 will meet these requirements. Programs entering FRP and not entering LRIP should be achieving MRL 9 requirements.

3.3.5.1 LOW RATE INITIAL PRODUCTION

Tracking and managing manufacturing maturity progress toward MRL 9 for the overall program should be a significant part of program management activity during LRIP. Manufacturing risk management and progress toward MRL 9 should be a normal part of program reviews. The results of the final MRA performed during EMD will be used as a baseline reference.

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 FRP.

The FRP decision milestone requires that manufacturing risk is understood and that the manufacturing processes for the system be capable, in control, and affordable. A formal MRA should be performed near the end of LRIP to prepare for the FRP decision. The timing of the review should be such that the results will be available to the MDA at least 60 days prior to the scheduled decision point. As in the earlier reviews, the team for this review should be composed of program office manufacturing personnel selected by the Program Manager and may include may include other subject matter experts and objective members who are not part of the program team. The core of the team should be comprised of manufacturing subject matter experts.

The resulting MRA report should:

1. For each evaluation area (process, component, assembly, subsystem, etc.), describe the technology, the hardware that will require the technology and the rationale.

2. For each appropriate element, identify the capability of companies and facilities to manufacture items that require the technology.

3. Describe how well each appropriate element conforms to MRL 9 requirements for each MRL thread and discuss the basis for the assessment.

4. Discuss how overall program preparations compare to MRL 9 criteria for each MRL thread.

5. Highlight any areas where an element or a key program-level manufacturing preparation area falls short of MRL 9 requirements; discuss the risks that these shortfalls pose to the program, and discuss the status of efforts to mitigate those risks.

6. Estimate the schedule or funding changes required to correct any significant shortfalls.

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

a. Request a delay in the full rate production decision point to allow time to mature the technology and/or manufacturing process.

b. Select alternative, more mature technologies and/or manufacturing processes.

c. Carry immature technologies or program-level manufacturing preparations (unusually high levels of risk) into the full rate review and submit a Manufacturing Maturation Plan (highlighting approach, time and funding required) along with the results of the MRA.

The only systems engineering review normally conducted during LRIP is the Operational Test Readiness Review (OTRR).

3.3.5.2 FULL RATE PRODUCTION

Although formal MRAs are not normally performed in this phase, significant management attention should be devoted to moving the program maturity level to MRL 10 through continuous process improvement efforts. Management reviews should examine progress toward MRL 10 in each of the dimensions of the MRL threads. When MRL 10 is achieved, management effort will be required to maintain the program at MRL 10 to support the remaining production and system modification programs that may occur.

Manufacturing processes should be under control as an entry criterion for full rate production. During FRP, significant management attention must be applied to implementing the planned rate capability. This could include tooling, trained manpower, and specialized test equipment.

Section 4: Manufacturing Readiness Assessments

4.1 INTRODUCTION

This section will provide guidance and describe best practices for performing Manufacturing Readiness Assessments (MRAs) and using the results.

An MRA is an important tool for evaluating manufacturing maturity and risk that is most useful in the context of a broader manufacturing risk management process. In other words, MRAs should lead to action; setting goals for increased manufacturing maturity/reduced manufacturing risk; creating action plans and funding estimates to reach those goals; reaching decisions about the readiness of a technology/process to transition into a weapon system design or onto the factory floor; and reaching decisions on a weapon system's readiness to proceed into the next acquisition phase.

An MRA measures against a standard or goal. MRL descriptions are the standards, but they are not a simple go/no-go gauge. MRA results generally do not support the idea of assigning a single MRL to an entire technology or weapon system. Even in a relatively simple case, where an MRA 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. This can be effective for the simplest technology elements, but for more complex technologies or weapon systems this approach could be misleading and give the impression of an overall level of risk greater than is really the case. When MRAs evaluate 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 MS B.

To have a manageable level of manufacturing risk, there is an expectation of a nominal MRL that the elements of a technology or weapons system should have achieved for a given point in its life cycle. (e.g. MRL 6 at MS B, MRL 8 at MS C, etc.). That expected/nominal value is used as a standard against which the maturity of a technology or weapon system is measured. Two key pieces of knowledge are required to decide if a technology or weapon system is ready to move to the next phase of its life cycle.

- Which elements (technologies, components, assemblies, subsystems, etc.) have not reached the nominal MRL value.

- Understanding 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.

A manufacturing maturity shortfall in an element can be easy or difficult to fix. Understanding the difference and how that drives manufacturing risk for the program is a dimension of the MRA activity that is the most demanding.

In summary, an MRA:

- Compares the status of the key program elements to a nominal MRL appropriate for the stage of the program.

- Describes the risk associated with elements that fall short of the standard.

- Lays the foundation for manufacturing risk mitigation planning and investment.

4.2 BASIC STEPS IN AN MRA

This section will provide key steps in the process of conducting an MRA. There can be one or more reasons to conduct this type of analysis. For example, an MRA can be used during an early materiel analysis phase or during source selection prior to MS A to expand the considerations of a particular prototype design. 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.

MRAs can aid in determining the maturity of the design relative to the offeror's ability to achieve projected cost or schedule targets. Figure 4.1 outlines a sample flow that has been used to conduct assessments on ATDs (focusing on one key technology area or component) and on acquisition programs requiring an overall system look. One key difference is, in applying the assessment at the system level, it is necessary to examine integration activities such as assembly and test processes. When a subsystem and/or component (e.g. battery/circuit card) is built by a prime contractor or supplier, both assembly and test processes will be examined in an integrated process flow. At the system level (e.g. missile), these components require assembly processes, intermediate test processes, and final assembly acceptance testing. All levels must be considered to effectively gauge the ability of the offeror to meet projected cost and schedule targets.

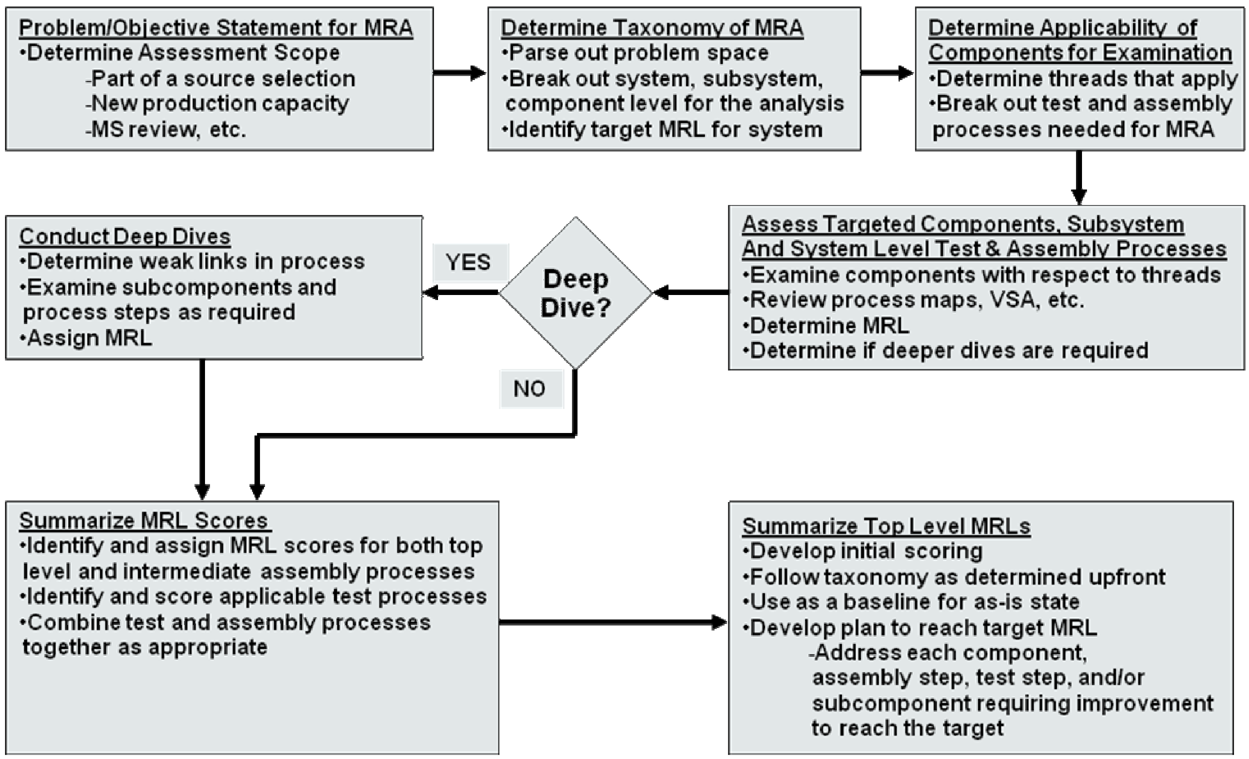


Figure 4.1: Sample Flow for an MRA Process

4.2.1 ORIENTATION OF PROGRAM PERSONNEL

Because these are relatively new concepts, program personnel (government and contractor) are likely to need an orientation to MRLs and MRAs to make their participation more effective. To facilitate this orientation the MRL definitions, threads, tutorials, tools and other information can be found on the Defense Acquisition University website found in Appendix D.

4.2.2 PLANNING AND PREPARATION

Effective scoping of the MRA process is vital. Is the MRA part of a source selection? Is it for new product capability? Is it for current production yields? Each direction would infer a different expectation for the MRA. For example, in a source selection, the government would identify MRL targets for given milestones over an extended time period. The granularity of the response for achieving an MRL target would be greater for an early milestone, but lack detail for future ones. This would be due to the lack of detail about the targeted design and how the offeror intends to accomplish the key performance parameters. The same MRA process could be followed with details being filled in to complete a thorough Manufacturing Maturity Plan. Typically, MRLs will track behind TRLs. However, early examination of the producibility of the proposed design allows for trades on cost, performance, and schedule to be accomplished early in the design cycle when the impact is significantly lower. If the MRA is being conducted on a mature production line, then emphasis will be placed on understanding what the theoretical production capacity is, the ability to meet a projected rate and to determine what investments (capital, increased manpower, and floor changes) may be needed to meet a surge requirement.

The MRA activity needs to identify the critical technology and component areas (elements) to focus on for on-site assessment. It is rarely feasible to visit every supplier of every material, component and assembly to examine the status of their key manufacturing processes. Those elements that will not be assessed on-site need alternative approaches. 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.
- Known significant problems or risks (low yields, high costs, immature manufacturing processes, etc.) exist.

In planning for an MRA, the contractor and the government will determine the focus areas. This step is extremely important. There must be an agreement on how the offeror (if in source selection) or contractor intends to define system, subsystem and/or component levels of interest. This will serve as the reporting template for the assessment and set expectations on the scope and depth of the proposed analysis. Additionally, the appropriate target MRL should be defined for the system at the current phase of the program.

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

In order to be effective in helping to plan an MRA, the MRA team members from outside the program being assessed will need to familiarize themselves with the program. They will need to understand the purpose of the MRA, the objectives and status of the program, Critical Technology Elements, configuration of hardware, 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 personnel.

The MRA team, contractor and government, determines the MRL threads (which help to define what is the appropriate level to assign) that apply for the appropriate system, subsystem, and/or component, and identifies the needed system level test and assembly processes that require an MRL assignment. This does includes test and assembly steps that would be included in a sub-system 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. Finally, there is a system level checkout at a final integration or acceptance test cell.

The MRL threads contain evaluation criteria intended to focus specific questions to determine manufacturing maturity. These threads have different applicability or effect at various times during a product development life-cycle. The threads also serve as a guide or completeness check to cue the assessment team to areas for examination. The threads can apply at each component or subsystem value stream, component and eventually at the program level.

Timing of MRA events is typically driven by a variety of considerations: timing of acquisition milestone reviews or program baseline reviews; availability of qualified team members; contractor scheduling concerns; and other reasons as described in previous sections.

4.2.3 MRA Planning Best practices:

The list of best practices for MRL Planning and Management is continually growing based upon the increased number of MRLs performed each year. The authors have provided the following activities as a starting point for this Deskbook, and additional best practices will be captured and documented in the DAU MRL website (Appendix D).

The Program Office should contact the appropriate office of the Defense Contract Management Agency (DCMA) to gather information they have 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.

Orient the contractor(s) to be assessed well in advance of the visit. This can involve including contractor personnel in planning meetings as well as sending the contractor an orientation package that includes:

- The MRL definitions and threads.
- Directions to additional materials on the DAU website (Appendix D).

- Basic self-assessment questions.
- The readiness questions the MRA assessment team will use.
- An indication of technologies or processes of special interest.
- A strawman agenda for the assessment visit.

Ask the contractor(s) to do a self-assessment using the same criteria that will be used by the assessment team and be prepared to brief the results to the assessment team when they are on-site. The self-assessment should address the following basic questions:

- What is the current MRL for each of the key technologies you are developing and each key manufacturing process you will use?
- 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?
- In the case of an ATD or ACTD or in the Technology Development Phase of an acquisition program, what MRL would be sufficient for your company or an OEM using your technology to commit to it in a product baseline design?

For companies that provide key components or subassemblies and for which an MRA site visit is not feasible, the contractor should be asked to provide a written self-assessment which should be analyzed by the assessment team.

Set expectations for team members:

- Format and timing of reporting their results to the team.
- Standards of behavior at the contractor's facility.
- Personal preparation.
- The need for a detailed understanding in their assigned area and the role shop floor observations and off-line discussions with contractor personnel play.
- Responsibilities after the on-site review is completed.

Make arrangements with the contractor for a government team meeting room to be available where private discussions can be held and team members can record their observations while they are fresh.

Make arrangements with the contractor for government team members to bring computers into the facility to facilitate the capture of their observations in electronic format.

Invite other objective team members and manufacturing subject matter experts to participate in the MRA process, as appropriate.

4.3 CONDUCTING THE MRA

DoD's MRL definitions (Appendix A) and the supporting detailed thread definitions (Appendix B) are the basic standard of measurement for MRAs. A series of knowledge based questions derived from the MRL definitions and threads are typically used to guide the assessment process and gauge the MRL of specific technology elements that are embodied in hardware (e.g. materials, components, assemblies, subsystems). An extensive set of such questions, which address each thread for each MRL, has been developed by a joint DoD/industry group that can be tailored to any program (Appendix D).

When conducting an MRA, there should be a well-defined hierarchy starting at the system level flowing down to the lowest component that forms the smallest unit for examination. The assessment team can now initiate focused dialog at the component, test, and/or assembly process based on complexity, location, personnel availability, etc. The important point is to have the problem space completely mapped out, a hierarchy agreed to, and scope of the assessment identified. The MRL threads can now be used to guide examination of various data sources like process maps, work instructions, factory tours, etc., to assign an MRL to a technology, component, or subsystem. During the assessment process, a component or sub-system may be found to be more complex than originally thought, so a more detailed analysis, referred to as a 'deep dive' may be warranted.

For a small ATD, an MRA 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 much larger team not all of whom will go to every site.

Site visits are intended to provide a more detailed understanding than can be gained from briefings and documents. MRAs 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 and orientation to the facility.

2. Introduction of assessment team and contractor personnel.

3. Government 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 Government assessment team to record and discuss observations.

8. Out-briefing by Government team to contractor.

The visit team should be identify the readiness status of the key technologies and processes. They should also be gathering impressions of what actions would be necessary to bring readiness up to the target level in time to transition a technology or support a milestone decision with manageable risk.

If it is determined further examination of critical components is necessary, the MRA threads are applied at that level. Sub-components are examined along with process steps, and an MRL is determined for this final sub-tier level. A bottoms-up assessment of the relative manufacturing maturity of a system against program goals and objectives must be accomplished 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 Figure 4.1. Each MRL (at any level) should be identified. MRL criteria can be used throughout the supply chain and will provide insight into specific material risks.

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.

After completing the initial MRA, the resulting score (Fig. 4.2) should act as a baseline for the as-is state. The next steps are to develop a plan to reach the target MRL as defined earlier in the assessment process, including plans to address each component, assembly step, test step, and/or sub-component requiring improvement to reach the target. The MMP is ultimately the most important output of the analysis. The MRL assignment gives the users a way to quickly relay the maturity of the targeted manufacturing processes, producibility of a given design, and areas that need attention. The plan to reach a target MRL contributes to risk reduction for a program to achieve the identified cost, performance, and schedule goals.

Component Seeker	Top Level MRL	Observations	Most Critical
Front End Sensor	3	• Lacking details on builds • Process procedures need more work • Test and assembly procedures have not been verified in manufacturing environment	• Detector from supplier A – Design & production issues – No alternate source
Data Processing PWB	3	• New processor architecture • Awaiting Design for Manufacturing and Assembly (DFMA) results	• Low yields on initial build • Working process controls • Looking at re-design for easier fabrication
Cables For: Power Data	3	• Using same suppliers other weapon systems • Have not received prototypes, awaiting supplier delivery	• Re-validate manufacturing process as seen on past programs • Need new process plan
Housing	4	• New supplier: limited experience • Need new assembly processes at the prime	• Need supplier management process; need new process plans
Cooling	3	• Form, fit factors for new cooling design not in place • Initial process plan for build in place	• Final cooling plan will be defined after front end is stable
Integration Process that includes assembly and test	3	• Several new test processes need development for new components	• New test strategy and plan • New special test equipment must be ordered

Figure 4.2: Sample Summary Roll-Up of Components

4.3.2 MRA Execution Best Practices:

- In larger assessments, assign specific technologies, assemblies, subsystems or processes to individuals or sub teams.

- Let the contractor know in advance if there are high-interest areas where you know that shop floor visits and/or discussions with contractor experts will be desired.

- While on site, team members should seek documentation that supports contractor self-assessment results in key areas (e.g. plans, yield data, reports, briefings, work instructions, etc.) and obtain copies for later review when feasible.

- Near the end of the MRA, make a provision for the team to meet at the contractor's facility to capture their impressions in electronic format and discuss their observations on strengths and weaknesses with the rest of the team.

- Where 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.

- Provide an out-brief to the contractor highlighting strengths and weaknesses observed compared to expected MRL; reviewing any action items; and recognizing the contractors' hospitality and cooperation.

4.4 FINALIZING THE MRA REPORT

Usually some analysis is required by the MRA team after site visits are complete to clearly define the manufacturing maturity 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. In the case of an ATD, the report is used by the program Integrated Product Team (IPT) to either create a plan to increase manufacturing readiness/maturity sufficiently to support technology transition or to demonstrate to transition customers that the technology is in fact ready for transition.

In the case of an acquisition program, an MRA report that is performed to support a milestone decision is used internally by the program office as the basis for their recommendations to the Milestone Decision Authority and to create manufacturing risk mitigation plans and manufacturing maturation strategies for the next phase of acquisition. The MRA report will be provided to DoD for use in the milestone decision process at least one month prior to the scheduled milestone review. An acquisition program MRA report that is not in direct support of a milestone decision (e.g. perhaps near the beginning of an acquisition phase) is generally used to establish a manufacturing maturity baseline that can be used to create detailed plans and goals for manufacturing readiness improvement throughout the duration of the current acquisition phase and beyond.

MRA reports should contain the following basic elements:

1. A description of the technology which identifies the key elements; the key objectives of the technology development effort; and a discussion of the current state of the art.

2. Identification of the current TRL of the key technology elements.

3. A discussion of the companies which are responsible for the key technology elements.

4. A list of team members.

5. Dates and locations of site visits.

6. A description of the manufacturing processes for the key technology elements.

7. The assessed MRL for each key process or hardware element.
8. Areas where manufacturing readiness falls short of target MRL.
    - Identify key factors.
    - Define driving issues.
9. Identify programs and plans to reach target MRL.
10. Assess type and significance of risk to cost, schedule or performance.
11. Assess effectiveness of current risk mitigation plans.
    - Address right issues?
    - Timely?
    - Adequately funded?
    - Probability of success?
    - Options for increased effectiveness?

An appropriate target MRL definition (current or future state) should be selected for the program based on the appropriate phase and used as a standard for comparison. Areas where the current maturity level does not meet the requirement of the standard should be discussed in detail; defining potential program downside risks and impacts; and also defining necessary mitigation efforts, their costs, time requirements and their status. If the report is intended to support a milestone decision, it should provide rationale to decision authorities that will help them decide if the program has acceptable manufacturing risk to move into the next phase.

4.5 DEVELOPMENT OF A MANUFACTURING MATURATION PLAN (MMP)

The program office is required to prepare an MMP that covers all manufacturing risk areas. The MMP is delivered along with the MRA report for all milestone reviews. The following outline for a MMP includes the most essential items in planning for the maturity of a specific technology/process:

1. Title
2. Statement of the problem
    - Describe the technology/process and its maturity status.
    - Describe how this technology/process would be used in the system.
3. Solution options

- Benefits of using the preferred technology/process.
- Fall-back options and the consequences of each option.

4. Maturation program plan with schedule and funding breakout.
5. Describe key activities for the preferred technology/process.
6. Describe preparations for using an alternative technology/process.
7. Show the latest time that an alternative technology/process can be chosen.
8. Status of funding to perform this technology/process maturation.
9. Specific actions to be taken (what will be done and by whom).
10. What prototypes or test articles will be built?
11. What tests will be run?
    - How does the test environment relate to the operational environment?
12. What threshold performance must be met?
13. What MRL will be achieved and when will it be achieved?

Section 5: Manufacturing Risk Management

5.1 INTRODUCTION

A key product resulting from an assessment of manufacturing readiness is the Manufacturing Maturation Plan, which address the manufacturing risk and provides a mitigation plan for each risk area which continues throughout the life cycle of the program. The following sections describe the activities requires to properly address the capture and documentation of risk and the associated mitigation plans.

5.2 IDENTIFYING RISK AREAS AND DEVELOPING MITIGATION PLANS

The concept of MRLs is founded in risk mitigation. The purpose of an MRA is to identify manufacturing risk. Identifying risk assists the Program Manager (PM) in creating a plan or options to reduce or remove risks. MRAs also allow a clear view of a program's manufacturing risk and development of mitigation plans. Identifying risk is a key part of developing risk mitigation efforts making a program stronger and better able to move forward. Risk management includes risk planning, risk assessment, risk handling and mitigation strategies, and risk monitoring approaches.

When identifying risk areas, the PM should assess the risks of lower-tier MRLs (components and parts) for subsequent higher-order risk mitigation efforts. There is no magic formula for rolling up the effects of components, assemblies, and/or subsystems into one system-level metric. One option is to establish weighted guidelines to take into account the criticality of high risk areas. It is important to understand that a single high risk area could be a program-level cost, schedule and/or performance driver.

For high risk areas where MRLs are not meeting targets, mitigation plans should be developed by the PM, to include:

- Identify system, subsystem, or component.
- Describe the manufacturing problem.
- Assess program impacts (cost, schedule, and technical risks).
- Develop alternative solutions.

The PM should realize that 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 from development to manufacturing. As a result of risk identification, the PM can formulate and execute mitigation plans before the risks become severe. A useful reporting tool developed by the DoD ManTech community is shown in Figure 5.1. It is a powerful visual for significant reviews and audits to capture MRL status on key system components. The vertical axis denotes risk and the horizontal axis shows program milestones. Each line represents the ‘burn down’ plan for key system components of a notional program. The numbered ‘bubbles’ represent the mitigation steps (alternative solutions) at the given juncture.

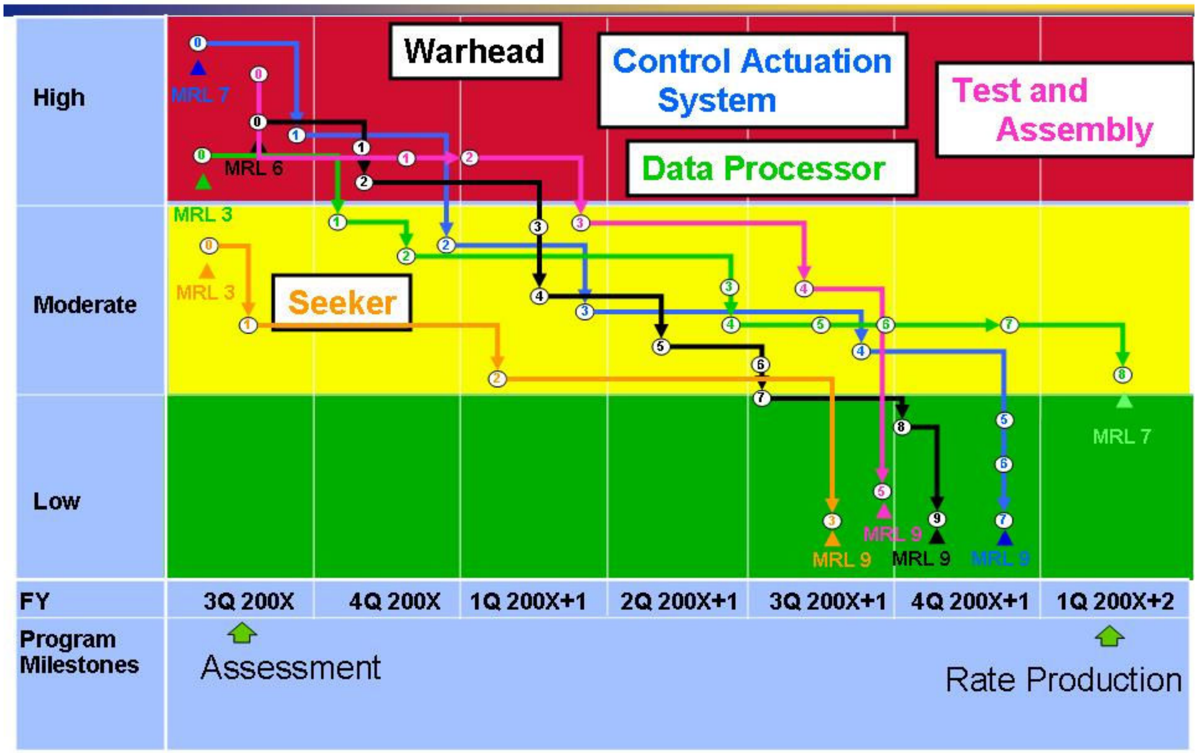


Figure 5.1: Sample MRA Risk Management Waterfall

5.1.1 BEST PRACTICES FOR S&T MANAGERS

Lead in sentence or paragraph

- Recognize that mitigating manufacturing risk can be the key ingredient of success in transitioning the technology they are developing.
- Accept manufacturing risk management as a basic responsibility of their jobs, on a par with technology risk management.
- Assess, plan, budget, and manage to reach manufacturing maturity targets.
- Incorporate manufacturing progress monitoring in management reviews and progress reporting.

- Work with transition customers (government and industry) to identify target MRL needed to support transition and incorporate those into the technology transition plan for the ATD.

- Tap the manufacturing expertise that is available in the Service/Agency ManTech programs.

- Review the manufacturing readiness information and tools available on the Defense Acquisition University website (Appendix D).

5.1.2 BEST PRACTICES FOR ACQUISITION MANAGERS

Lead in sentence or paragraph

- Accept the requirement to do MRAs as an opportunity to increase the probability of program success and integrate it into a broader management effort to control manufacturing risk.

- Recognize manufacturing risk and readiness as key factors in reaching program cost, schedule and performance goals.

- Incorporate the management of manufacturing readiness and risk into the basic fabric of managing the program.

    - Setting goals for manufacturing readiness.

    - Establishing plans for manufacturing maturation and risk mitigation and budgeting for their execution.

    - Assessing status and reviewing progress.

    - Assuring access to trained and experienced manufacturing subject matter experts.

- Do not rely totally on contractor manufacturing assessments any more than you would rely totally on contractor technology or engineering assessments.

- Keep in mind that an MRA that does not lead to actions or support decisions is largely a wasted effort.

- Know the MRL of any technology being considered for application to the weapon system.

- Do not allow a technology to be baselined into the system in EMD unless it has reached an appropriate level of manufacturing readiness (normally MRL 6) or has a solid risk mitigation plan.

- Incorporate the examination of manufacturing maturity into other scheduled engineering or program management reviews.
- Assess and understand manufacturing readiness and risk early in each phase of an acquisition program to establish a baseline.
- Set manufacturing readiness targets and manage to reach those targets.
- Use the Defense Contract Management Agency (DCMA) as a source of information about strengths and weaknesses in the contractor's manufacturing operations.
- Use the manufacturing expertise available on product center manufacturing staffs and within your Service/Agency Manufacturing Technology programs to supplement your staff.
    - A list of technology transition programs are included in the Manufacturing Readiness Guide available on the Defense Acquisition University website (Appendix D)
- Support manufacturing training for members of your program staff
- Review the manufacturing readiness information and tools available on the Defense Acquisition University website (Appendix D)
- Include contractual Statement of Work (SOW) tasking (see Section 6) for the prime contractor and suppliers to support conducting MRAs. Also include contractual SOW taskings for best practices that improve producibility, quality, and affordability and enable the assessment of manufacturing maturity.

5.2 MANUFACTURING RISK SUMMARY

Identification of risk allows for risk mitigation planning and is a goal of the MRA to achieve manufacturing readiness. MRLs will aid managers in identifying potential risk areas as a program progresses through development. PMs can use MRLs throughout the risk management and mitigation process as defined within the DoD S&T and Acquisition process. In general, risks associated with performance, cost, and schedule are comprehensively listed, evaluated and a mitigation plan with multiple mid-term checks is developed. MRLs are used within the risk mitigation process to evaluate and check on progress. For further information on risk management you should look at:

- DoD Risk Management Guidebook at http://www.acq.osd.mil/sse/ed/docs/2006-RM-guide-4Aug06-final-version.pdf
- DoD Risk Management Community of Practice at https://acc.dau.mil/RM

- Risk Management Continuous Learning Management Module at https://learn.dau.mil/html/clc/Clc1.jsp?cl and select CLM 017.

Section 6: Applying MRLs in Contract Language

6.1 INTRODUCTION

This section gives some ideas and strategies for ensuring MRLs and MRAs are treated effectively as a part of a program's acquisition activities.

Like all program requirements, MRLs and MRAs must be placed in contract language to be effective. Although most of the discussion in this section is oriented towards competitive acquisitions, the recommendations for Statement Of Objectives (SOO) and SOW language also apply to sole source programs with manufacturing requirements. During the initial stages of acquisition planning and risk identification, the program team should determine if manufacturing requirements are applicable to the planned program. If hardware is being manufactured, the two key drivers in determining what manufacturing requirements exist are the current phase of the program and its overall complexity. Once manufacturing requirements are identified the team can then assess whether manufacturing requirements and manufacturing risk will be significant discriminators for the source selection. Discriminators are those key requirements or program risks that separate offerors from each other during the proposal evaluation process. If the program team determines that manufacturing readiness will be a discriminator between offerors, then MRL 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, MRAs should be included in the SOO and in the resulting SOW, so it can be a formal part of the contract. The acquisition team must determine what MRL will be required at the completion of the phase (e.g., MRL 8 for MS 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.

6.2 MRAs & MRLs in RFP Language for Competitive RFPs

If manufacturing readiness is a requirement and is determined to be a discriminator, the RFP for a program should require the offeror's proposal to document the results of a manufacturing readiness assessment against the MRL definition appropriate for the current phase of the program. Based on the assessment, the offeror's proposal should identify the current MRL and then give an explanation of how they will move the program forward and achieve the required MRL by the end of the program phase (e.g., MRL 8 for MS C). Allowing the offeror to select the methodology of their MRA would minimize the required activity, and allow the Program Office to see what the offeror believes they have achieved and also what the offeror thinks are the appropriate set of manufacturing tasks for the phase. For MRLs assessed below the MRL required at the end of the phase (e.g., currently at MRL 6 vs. MRL 8 required), the offeror's proposal should document how they plan to achieve the required MRL. 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 required MRL. This would put both the offeror and government on the same page when discussing the program's manufacturing risks and plans.

Example scenario for program entering Technology Development Phase: *The RFP would have required offerors to prepare an overall, initial assessment. The offerors shall have conducted a preliminary MRA using the MRL 4 Definitions found in the DoD MRA Deskbook. The results of this MRA shall be discussed in the proposal along with the methodology the offeror used in conducting the MRA. The offeror shall provide an MMP, which will discuss how they will move the program 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 during the program and all risk mitigation efforts that will be necessary to achieve the final MRL 6 definition at the end of the program. The offeror shall discuss where the MRL 5 and 6 definitions will be achieved within their plans and schedules.*

6.3 MRAs in RFP Language for Source Selections

Three key sections need to be addressed in the RFP for source selection programs: Section L (Instructions to Offerors), Section M (Evaluation Criteria), and the Statement of Objectives. Sections L and M should only be inserted if manufacturing readiness will be a key discriminator in the source selection. The RFP documentation must track from the contract requirement in the SOO (e.g. the requirement to achieve a specific MRL or to conduct periodic MRAs during the contract period of performance) to Section M (the criteria stating how the evaluation team will evaluate the offeror's proposal to meet or exceed the requirement) to 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). The SOO language should be included in all RFPs.

Section L sample language:

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

The offeror's proposal shall clearly and specifically identify their current Manufacturing Readiness Level for their program using the criteria and process identified in the DoD MRA Deskbook (*see* https://acc.dau.mil/ComunityBrowser.aspx?id=182129&lang=enUS *include deskbook in RFP library of referenced documents)*. The contractor shall describe the approach used to assess their MRLs.

For any MRL that is assessed below MRL (TBD), the offeror shall identify the current MRL, the supporting rationale for the assessment, and provide 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 for assessing manufacturing readiness, their current MRL, as described in the DoD MRA Deskbook, and the adequacy of the offeror's plans to achieve the target MRL

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 Milestone Decision Authority. The Government will not evaluate proposal risk for this sub-factor.

Measure of Merit:

This sub-factor is met (i.e. acceptable) when the offeror's proposal clearly identifies and substantiates their MRL assessment and has clearly demonstrated they understand what is required to achieve the target MRL by the end of the program.

6.4 SOO Language for all RFPs:

The offeror shall conduct Manufacturing Readiness Assessments to asses MRLs throughout the program using the DoD MRA Deskbook as a guide. The locations and frequencies of the MRAs will be specified in a SOW appendix. The offeror shall assume that the government will lead the MRA at the prime contractor and the prime contractor will lead MRAs at the suppliers with government participation. The offeror shall address how MRLs will be monitored to ensure achieving the required level in accordance with their Manufacturing Maturity Plans.

6.5 MRA SOW Language for Contracts

The contractor shall conduct Manufacturing Readiness Assessments using the definitions, criteria, and processes defined in the DoD MRA Deskbook as a guide. MRAs will be conducted at the locations and frequencies specified in Appendix TBD. MRAs will be led by the program office at the prime contractor's facilities. The prime contractor shall lead MRAs at suppliers and include program office participants.

The contractor shall develop and implement manufacturing maturation plans for areas in which the MRL is lower than required to meet MS 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 and process changes have occurred which could impact the MRL.

6.6 Summary

This section contains methods and examples on how to effectively implement the MRA process contractually in your program. As mentioned above, it is essential that you perform a detailed acquisition strategy plan addressing both complexity and acquisition phase. These examples are meant to be tailored to your specific needs. The MRA process will be an effective tool for supporting the risk management process and should be coordinated to the maximum extent possible with other technical reviews and audits.

APPENDICES

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A.

DoD MANUFACTURING READINESS LEVEL DEFINITIONS

MRL	Definition	Description	Phase
1	Basic Manufacturing Implications Identified	This is the lowest level of manufacturing readiness. Basic research expands scientific principles that may have manufacturing implications. The focus is on a high level assessment of manufacturing opportunities. The research is unfettered.	Pre Materiel Solution Analysis
2	Manufacturing Concepts Identified	Invention begins. Manufacturing science and/or concept described in application context. Identification of material and process approaches are limited to paper studies and analysis. Initial manufacturing feasibility and issues are emerging.	Pre Materiel Solution Analysis
3	Manufacturing Proof of Concept Developed	Conduct analytical or laboratory experiments to validate paper studies. Experimental hardware or processes have been created, but are not yet integrated or representative. Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required.	Pre Materiel Solution Analysis
4	Capability to produce the technology in a laboratory environment.	Required investments, such as manufacturing technology development identified. Processes to ensure manufacturability, producibility and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks identified for prototype build. Manufacturing cost drivers identified. Producibility assessments of design concepts have been completed. Key design performance parameters identified. Special needs identified for tooling, facilities, material handling and skills.	Materiel Solution Analysis (MSA) leading to a Milestone A decision.
5	Capability to produce prototype components in a production relevant environment.	Mfg strategy refined and integrated with Risk Mgt 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 initiated or ongoing. Producibility assessments of key technologies and components ongoing. Cost model based upon detailed end-to-end value stream map.	Technology Development (TD) Phase.
6	Capability to produce a prototype system or subsystem in a production relevant environment.	Initial mfg approach developed. Majority of manufacturing processes have been defined and characterized, but there are still significant engineering/design changes. Preliminary design of critical components completed. Producibility assessments of key technologies complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on subsystems/ systems in a production relevant environment. Detailed cost analysis include design trades. Cost targets allocated. Producibility considerations shape system development plans. Long lead and key supply chain elements identified. Industrial Capabilities Assessment (ICA) for MS B completed.	Technology Development (TD) phase leading to a Milestone B decision.
7	Capability to produce systems, subsystems or components in a production representative environment.	Detailed design is underway. Material specifications are approved. Materials available to meet planned pilot line build schedule. Manufacturing processes and procedures demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments underway. Cost models updated with detailed designs, rolled up to system level and tracked against targets. Unit cost reduction efforts underway. Supply chain and supplier QA assessed. Long lead procurement plans in place. Production tooling and test equipment design & development initiated.	Engineering & Manufacturing Development (EMD) leading to Post CDR Assessment

8	Pilot line capability demonstrated. Ready to begin low rate production.	Detailed system design essentially complete and sufficiently stable to enter low rate production. All materials are available to meet planned low rate production schedule. Manufacturing and quality processes and procedures proven in a pilot line environment, under control and ready for low rate production. Known producibility risks pose no significant risk for low rate production. Engineering cost model driven by detailed design and validated. Supply chain established and stable. ICA for MS C completed.	Engineering & Manufacturing Development (EMD) leading to a Milestone C decision.
9	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.	Major system design features are stable and proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing processes and procedures are established and controlled to three-sigma or some other appropriate quality level to meet design key characteristic tolerances in a low rate production environment. Production risk monitoring ongoing. LRIP cost goals met, learning curve validated. Actual cost model developed for FRP environment, with impact of Continuous improvement.	Production & Deployment leading to a Full Rate Production (FRP) decision
10	Full Rate Production demonstrated and lean production practices in place.	This is the highest level of production readiness. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in rate production and meet all engineering, performance, quality and reliability requirements. All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. FRP unit cost meets goal, funding sufficient for production at required rates. Lean practices well established and continuous process improvements ongoing.	Full Rate Production/ Sustainment

Definitions of Terms Found in Manufacturing Readiness Level Definitions

Production relevant environment – An environment normally found during MRL 5 and 6 that contains key elements of production realism not normally found in the laboratory environment (e.g. uses production personnel, materials or equipment or tooling, or process steps, or work instructions, stated cycle time, etc.). May occur in a laboratory or model shop if key elements or production realism are added.

Production representative environment – An environment normally found during MRL 7 (probably on the manufacturing floor) that contains most of the key elements (tooling, equipment, temperature, cleanliness, lighting, personnel skill levels, materials, work instructions, etc) that will be present in the shop floor production areas where low rate production will eventually take place.

Pilot line environment – An environment normally found during MRL 8 in a manufacturing floor production area that incorporates all of the key elements (equipment, personnel skill levels, materials, components, work instructions, tooling, etc.) required to produce production configuration items, subsystems or systems that meet design requirements in low rate production. To the maximum extent practical, the pilot line should utilize rate production processes.

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. Activities can include some or all of the following activities:

- Design for commonality and standardization- fewer parts
- Perform comprehensive Technology Assessment, including commercial industrial applications and the supplier base
- Design for Multi-Use and Dual-Use applications
- Design for modularity and plug compatible interface/integration
- Design for flexibility, adaptability, and “robust design”
- Utilize reliable processes and materials

Producibility – Is the capability of an item to be produced, including some or all of the following activities:

- Design to specific Cp-CpK process control parameters- six sigma
- Perform material characterization analysis
- Perform variability reduction analysis- Taguchi, DOE
- Develop critical materials and processes before selecting product design
- Utilize pervasive modeling & simulation for product and process design tradeoffs
- Design and deployment of closed-loop process-control on critical items

APPENDIX B.

DETAILED MRL DEFINITIONS (THREADS MATRIX) 1

Version 9.0	1-Apr-09										
DoD Manufacturing Readiness Levels (MRLs)											
Acq Phase		Pre Material Solution Analysis	Pre Material Solution Analysis	Pre Material Solution Analysis	Material Solution Analysis	Technology Development	Technology Development	Engineering & Mfg Development	Engineering & Mfg Development	Low-Rate Initial Production	Full-Rate Production
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
Technology & Industrial Base	Technology 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.
	Technology Transition to Production			Potential sources identified for technology needs. (Understand state of the art).	Industrial Base capabilities and gaps/risks identified for key technologies, components, and/or key processes.	Industrial Base assessed to identify potential manufacturing sources.	Industrial Capability Assessment (ICA) for MS B has been completed. Industrial capability in place to support mfg of development articles. Plans to minimize sole/foreign sources complete. Need for sole/foreign sources justified. Potential alternative sources identified.	Industrial capability to support production has been analyzed. Sole/foreign sources stability is assessed/monitored. Developing potential alternate sources as necessary.	Industrial Capability Assessment (ICA) for MS C has been completed. 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. Industrial capability assessed to support mods, upgrades, surge and other potential manufacturing requirements.
	Manufacturing Technology Development		New manufacturing concepts and potential solutions identified.	Manufacturing technology concepts identified through experiments / models.	Mfg Science & Advanced Mfg Technology requirements identified	Required manufacturing technology development efforts initiated.	Manufacturing technology efforts continuing. Required manufacturing technology development solutions demonstrated in a production relevant environment.	Manufacturing technology efforts continuing. Required manufacturing technology development solutions demonstrated in a production representative environment.	Manufacturing technology efforts continuing. Required manufacturing technology solutions validated on a pilot line.	Manufacturing technology efforts continuing. Manufacturing technology process improvements efforts initiated for FRP.	Manufacturing technology efforts continuing. Manufacturing technology continuous process improvements ongoing.
Design	Producibility Program			Relevant materials/processes evaluated for manufacturability using experimental results.	Producibility & Manufacturability assessment of design concepts completed. Results guide selection of design concepts and key components/technologies for Technology Development Strategy. Required Test Evaluation Strategy (TES) includes Design for Test during production.	Producibility & Manufacturability assessments of key technologies and components initiated. Systems Engineering Plan (SEP) requires validation of design choices against manufacturing process and industrial base capability constraints. Manufacturing Processes assessed for capability to test and verify in production, and influence on O&S.	Producibility assessments of key technologies/components and producibility trade studies (performance vs. producibility) completed. Results used to shape System Development Strategy and plans for SDD or technology insertion programs phase.	Detailed producibility trade studies using knowledge of key design characteristics and related manufacturing process capability completed. Producibility enhancement efforts (e.g. DFMA) initiated.	Producibility improvements implemented on system. Known producibility issues have been resolved and pose no significant risk for LRIP.	Prior producibility improvements analyzed for effectiveness during LRIP. Producibility issues/risks discovered in LRIP have been mitigated and pose no significant risk for FRP.	On-going producibility improvements analyzed for effectiveness. Producibility refinements continue. All mods, upgrades, DMSMS and other changes assessed for producibility.
	Design Maturity	Manufacturing opportunities identified.	Applications defined. Broad performance goals identified that may drive manufacturing options.	Top level performance requirements defined. Trade-offs in design options assessed based on experiments. Product lifecyle and technical requirements evaluated.	Initial Systems Engineering Plan and Test and Evaluation Strategy recognize the need for the establishment/validation of manufacturing capability and management of manufacturing risk for the product lifecycle. Initial Key Performance Parameters (KPPs) identified.	Identification of enabling/critical technologies and components is complete and includes the product lifecycle. Evaluation of design Key Characteristics (KC) initiated.	Basic system design requirements defined. All enabling/critical technologies/components have been tested and validated. Product data required for prototype manufacturing released. A preliminary performance as well as focused logistics specification is in place. Key Characteristics and tolerances have been established.	Product requirements and features are well enough defined to support detailed systems design. All product data essential for manufacturing of component design demonstration released. Potential KC risk issues have been identified and mitigation plan is in place. Design change traffic may be significant.	Detailed design of product features and interfaces is complete. All product data essential for system manufacturing released. Major product design features are sufficiently stable such that key LRIP manufacturing processes will be representative of those used in FRP. Design change traffic does not significantly impact LRIP. Key characteristics are stable and have been demonstrated in SDD or technology insertion program.	Major product design features are stable and LRIP produced items are proven in product testing. Design change traffic is limited to minor configuration changes. All KC's are controlled in production to three sigma or other appropriate quality levels.	Product design is stable. Design changes are few and generally limited to those required for continuous improvement or in reaction to obsolesence. All KCs are controlled to six sigma or other appropriate quality levels.

APPENDIX B.

DETAILED MRL DEFINITIONS (THREADS MATRIX) 2

DoD Manufacturing Readiness Levels (MRLs)											
Acq Phase		**Pre Material Solution Analysis**	**Pre Material Solution Analysis**	**Pre Material Solution Analysis**	**Material Solution Analysis**	**Technology Development**	**Technology Development**	**Engineering & Mfg Development**	**Engineering & Mfg Development**	**Low-Rate Initial Production**	**Full-Rate Production**
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**
Cost & Funding	**Production Cost Knowledge (Cost modeling)**		Cost model approach defined.	Technology cost models developed for new process steps and materials based on experiments.	Detailed process chart cost models driven by key characteristics and process variables. Manufacturing, material and specialized reqt. cost drivers identified.	Detailed end-to-end value stream map cost model for major system components includes Materials, Labor, Equipment, Tooling/STE, setup, yield/scrap/rework, WIP, and capability/capacity constraints. Component simulations drive cost models.	Cost model inputs include design requirements, material specifications, tolerances, integrated master schedule, results of system/subsystem simulations and production relevant demonstrations.	Cost models updated with detailed designs and features, collected quality data, plant layouts and designs, obsolescence solutions.	Engineering cost model driven by detailed design and validated with data from relevant environment.	Actual cost model developed for FRP environment. Variability experiments conducted to show FRP impact, potential for continuous improvement.	Cost model validated against actual FRP cost.
	Cost Analysis	Identify any manufacturing cost implications.	Cost elements identified.	Sensitivity analysis conducted to define cost drivers and production development strategy (i.e. Lab to Pilot to Factory).	Material, manufacturing, and specialized reqt. costs identified for design concepts. Producibility cost risks assessed.	Current state analysis of cost of design choices, make/buy, capacity, process capability, sources, quality, key characteristics, yield/rate, and variability.	Cost analysis of mfg future states, design trades, supply chain/yield/rate/SDD/technology insertion plans. Allocate cost targets. Cost reduction and avoidance contract incentives identified.	Costs rolled up to system level and tracked against targets. Detailed trade studies and engineering change requests supported by cost estimates. Cost reduction efforts underway, incentives in place.	Cost analysis of proposed changes to requirements or configuration.	LRIP cost goals met, learning curve validated.	FRP cost goals met. Cost reduction initiatives ongoing.
	Manufacturing Investment Budget	Potential investments identified.	Program/ projects have budget estimates for reaching MRL of 3 through experiment.	Program/ projects have budget estimates for reaching MRL of 4.	Manufacturing technology initiatives identified to reduce costs. Program has budget estimate for reaching MRL 5. All Risk Mitigation Plans required to raise deficient elements to MRL of 4 are fully funded.	Program has budget estimate for reaching MRL 6 by MS B. Estimate includes capital investment for Production-representative equipment. All Risk Mitigation Plans required to raise deficient elements to MRL of 5 are fully funded.	Program has budget estimate for reaching MRL 7 by CDR. All Risk Mitigation Plans required to raise deficient elements to MRL of 6 are fully funded.	Program has budget estimate for reaching MRL 8 by MS C. Estimate includes investment for Low Rate Initial Production. All Risk Mitigation Plans required to raise deficient sub systems to MRL of 7 are fully funded.	Program has budget estimate for reaching MRL 9 by the FRP decision point. Estimate includes investment for Full Rate Production. All Risk Mitigation Plans required to raise deficient sub systems to MRL of 8 are fully funded.	Program has budget estimate for lean implementation during FRP. All Risk Mitigation Plans required to improve deficient subsystems to MRL of 9 during FRP are fully funded.	Production budgets sufficient for production at required rates and schedule.
Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)	**Maturity**	Material properities identified for explotation.	Material properties and characteristics predicted.	Material properities validated and assessed for basic manufacturability using experiments.	Survey completed to determine if materials have been used before in a manufacturing environment. Preliminary plans in place to address producibility risks of new material.	Materials have been manufactured or produced in a prototype environment. Maturity efforts in place to address new material production risks for technology demonstration.	Material maturity verified through technology demonstration articles. Preliminary material specifications in place.	Materials maturity sufficient for pilot line build. Material specifications approved.	Materials proven and validated on System Demonstration and Development (SDD) production as adequate to support LRIP. Material specification stable.	Material is proven and controlled to specification in LRIP.	Material is proven and controlled to specification in FRP.
	Availability		Material availability assessed	Material scale-up issues identified.	Lead times have been identified for all materials. All exotic (difficult to obtain, process, or hazardous) materials identified.	Availability issues addressed for prototype build. Significant material risks identified for all materials. Planning begun to address scale-up issues.	Availability issues addressed to meet technology demonstration articles. SDD long lead time items identified. Obsolescence issues identified.	Availability issues addressed to meet SDD builds. Long Lead procurement identified/planned for Low Rate Initial Production. Obsolescence plan in place.	Long Lead procurement initiated for LRIP. Availability issues pose no significant risk for LRIP.	Long Lead procurement initiated for Full Rate Production (FRP). Availability issues pose no significant risk for FRP.	Program is in FRP with no material availability issues.
	Supply Chain Management			Initial assessment of potential supply chain capability.	Survey completed for potential supply chain sources.	Supply chain sources identified. Sole/single/foreign source vendors have been identified and planning has begun to minimize risks.	Supply chain plans in place (e.g., teaming agreements, etc.) leading to an SDD contract award.	Effective supply chain management process in place. Completed assessment of supply chain first tier.	Supply chain stable and adequate to support LRIP. Completed assessment of supply chain second tier.	Supply chain is stable and adequate to support FRP. Long term agreements in place where practical.	Supply chain proven and supporting FRP requirements.
	Special Handling (i.e. shelf life, security, hazardous materials, storage environment, etc.)		Initial evaluation of potential regulatory requirements and special handling concerns.	Special Handling procedures applied in the lab. Special handling concerns assessed. Material Safety Data Sheets (MSDS) prepared.	Special Handling procedures applied. Special handling requirements identified. MSDS reviewed and updated.	Special Handling procedures applied. Special handling requirement gaps identified. New special handling processes demonstrated in lab environment.	Special Handling procedures applied. Plans to address special handling requirement gaps complete.	Special Handling procedures applied. Special handling procedures developed.	Special Handling procedures applied. Special handling procedures demonstrated on SDD or Technology insertion Programs production. Special handling issues pose no	Special Handling procedures applied. Special handling procedures demonstrated in LRIP. Special handling issues pose no significant risk for FRP.	Special handling procedures effectively implemented in FRP.

APPENDIX B.

DETAILED MRL DEFINITIONS (THREADS MATRIX) 3

Version 9.0	1-Apr-09										
DoD Manufacturing Readiness Levels (MRLs)											
Acq Phase		Pre Material Solution Analysis	Pre Material Solution Analysis	Pre Material Solution Analysis	Material Solution Analysis	Technology Development	Technology Development	Engineering & Mfg Development	Engineering & Mfg Development	Low-Rate Initial Production	Full-Rate Production
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**
Process Capability & Control	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 & Simulation approaches for Process or Product are identified.	Initial simulation models (product or process) developed at the component level and validated.	Initial simulation models developed and validated at the technology, sub-system or system level.	Simulation models used to determine system constraints and identify improvement opportunities.	Simulation models verified by SDD Article build, results used to improve process and determine that LRIP requirements can be met.	Simulation model verified by LRIP build, assist in management of LRIP and determine that FRP requirements can be met.	Simulation model verified by FRP build. Production simulation models used as tool to assist in management FRP.
	Manufacturing Process Maturity		Identification of material and/or process approaches.	Document high level manufacturing processes. Critical manufacturing processes identified through experimentation.	Complete a survey to determine the current state of critical processes.	Maturity has been assessed on similar processes in production. Process capability requirements have been identified.	Manufacturing processes demonstrated in production relevant environment.	Manufacturing processes demonstrated in a production representative environment.	Manufacturing processes verified for LRIP on a pilot line. Process capability data being collected or estimated.	Manufacturing processes & procedures are established and controlled in production to 3-sigma or other appropriate quality level.	Manufacturing processes & procedures are established and controlled in production to 6-sigma or other appropriate quality level.
	Process Yields and Rates			Initial estimates of yields and rates based on experiments or state of the art.	Yield and Rates assessment on proposed processes complete and applied within AoA.	Target Yield and Rates established for production. Yield and Rate issues identified. Improvement plans developed/initiated.	Yields and Rates evaluated in production relevant environment. Improvement plans on-going and updated.	Yields and Rates estimated in production representative environment.	Yields and Rates required to begin LRIP verified using SDD articles.	Yield and Rates targets achieved. Yield improvements on-going.	Yield and Rates targets achieved. Yield improvements on-going.
Quality Management	Quality Management including Supplier Quality.				Quality strategy identified as part of the Technology Development Strategy.	Quality Strategy refined in the System Engineering Plan and Key Charactaristic are Identified during Technology Demonstrations.	Initial Quality Plan and Quality Management System is in place. Quality Risks and Metrics have been identified.	Quality targets established. Demonstrate ability to collect and analyse quality data (process and system) in the production representative environment.	Quality targets demonstrated on pilot line.	Quality targets verified on production line. Continuous Quality Improvement begins.	Quality targets verified on production line. Continuous Quality Improvement on-going.
Mfg Personnel				New manufacturing skills identified.	Mfg skill sets identified to overcome production barriers	Skill sets identified to meet prototype production runs. Special skills certification and training requirements quantified	Mfg workforce skills available for production in a relevant environment. Training resources identified for production workforce.	Mfg workforce resource requirements identified for Pilot Line. Training resources identified for special skills deficiencies and LEAN Six Sigma Training	Mfg workforce resource requirements identified for LRIP. Ability of mfg workforce to produce repeatable products and workforce quality measured; training initiated for certification on special skills	LRIP personnel requirements met. FRP personnel requirements identified..	FRP personnel requirements met. Production workforce skill sets maintained due to attrition of workforce.
Facilities				Specialized facility requirements/needs identified.	General industrial base (IB) capability identified for key technologies.	IB capabilities and gaps to support SDD and LRIP identified. Plan in place to fill gaps.	Mfg facility and facility development plans adequate to support SDD or Technology insertion Programs.	Facility capabilities for LRIP and FRP identified. Plan in place to fill gaps. Plant layout and design initiated.	Mfg facilities exist and are adequate to begin LRIP. Plans in place to support transition to FRP.	Mfg facilities in place and demonstrated in LRIP. and capacity plans adequate to support FRP decision.	Production facilities in place and capacity demonstrated to meet maximum FRP requirements. Executable facilities surge plan available.
Mfg Management	Mfg Planning & Scheduling				Mfg strategy developed and integrated with acq strategy. Prototype schedule risk mitigation efforts incorporated into TDS.	Mfg strategy refined. Prototype schedule risk mitigation efforts initiated.	Initial mfg approach developed. All system design related mfg events included in Integrated Master Plan/Schedule. Mfg risk mitigation approach for SDD or Technology insertion Programs defined.	Initial Mfg Plan developed. Mfg risks integrated into Risk Mitigation Plan.	Mfg Plan Completed. All key manufacturing risks have been validated & mitigated using SDD or Technology Insertion Program work products.	Mfg Plan updated and validated for FRP. All manufacturing risks have been validated and mitigated using LRIP articles.	All manufacturing risks have been validated and mitigated using FRP articles.
	Materials Planning				Parts list in development with associated lead time calculations.	Parts list maturing, make/buy evaluations ongoing; lead times, quality, cost and other risks identified.	Most material decisions made (make/buy), material risk identified and plans made to mitigate. BOM initiated.	Analyses for Make/Buy decisions & BOM complete. Material planning systems in place for Pilot Line build.	Make/Buy decisions & BOM complete to support LRIP. Material planning systems validated on Pilot Line build.	Make/Buy decisions & BOM complete to support FRP. Material planning systems validated on LRIP build.	Program is in FRP with only process improvement/obsolescence make/buy or BOM changes allowed. Material Planning Systems validated on FRP build.
	Tooling / Special Test and Inspection Equipment (STE/SIE)				Tooling / Special Test Equipment (STE) / Special Insptecion Equipment (SIE) requirements are considered.	Identify Tooling /STE/SIE reqts & provide supporting rationale and schedule.	Prototype tooling concepts demonstrated in relevant mfg environment.	Production tooling and STE/SIE design and development efforts initiated.	All Tooling , Testand Inspection Equipment proven on pilot line. Multiple tooling reqts identified for LRIP.	All Tooling, Test and Inspection Equipment proven on LRIP. Multiple tooling reqts identified for FRP.	Proven Tooling, Test and Inspection Equipment in place to support maximum FRP.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C.

MANUFACTURING READINESS CRITERIA FOR SYSTEMS ENGINEERING REVIEWS

Review Readiness Criteria (RRC) – Manufacturing (Top-Level) – 1 of 3

Milestone	Acquisition Phase	Sub-Phase	Review	Description of Review	Top-Level RRC	Verification/Certification Authority
A	Materiel Solution Analysis	N/A	Alternate System Review (ASR)	Program's technical baseline sufficient to support valid cost estimate	• Technology Development Phase plans effectively address manufacturing maturity risks/needs and industrial base capability • System alternative(s) selection(s) effectively consider manufacturing risk and cost • Program cost and schedule plans effectively address manufacturing risks	Joint government/contractor team conducts Manufacturing Readiness Assessments to identify current Manufacturing Readiness Level
			Initial Technical Review (ITR)	Requirements agree with customer needs and expectations	• System Manufacturing (MFG) cost drivers quantified • Uncertainty range for MFG cost drivers reflected in program baseline • Enabling/critical technologies are at a minimum of MRL 4 • Plans and budget for Technology Development phase sufficient to bring enabling/critical technologies to MRL 6	
B	Technology Development	N/A	System Requirements Review (SRR)	System requirements completely and properly identified	• Initial assessment of industrial base capabilities complete • Adequate plans in place to address industrial base capability issues • System-level producibility analysis completed • Manufacturing cost and schedule risks for EMD effectively assessed • Enabling/critical technologies at MRL 6 • EMD plans effectively address key manufacturing cost drivers, producibility issues and manufacturing maturity risks • Manufacturing plans and progress sufficient to support EMD	
			System Functional Review (SFR)	Functional baseline established to satisfy requirements	• Manufacturing schedules for EMD are executable within approved budget • Manufacturing-related skills and staffing are adequate to support EMD efforts • Manufacturing risks known and manageable for EMD	

Review Readiness Criteria (RRC) – Manufacturing (Top-Level) – 2 of 3

Milestone	Acquisition Phase	Sub-Phase	Review	Description of Review	Top-Level RRC	Verification/Certification Authority
	Engineering & Manufacturing Development	Integrated System Design,	Preliminary Design Review (PDR) should be performed prior to MS B	Design maturity sufficient to begin detailed design	• Second Industrial Capability Assessment complete • System assessed against MRL 6 • Producibility Enhancement Program initiated	Team validates current MRLs
			Critical Design Review (CDR)	Design and interfaces complete	• Second system-wide MRA complete, system assessed against MRL 7 • Critical process capabilities/plans support Design Key Characteristics • Quarterly production risk reviews commenced • Process control plans developed • Build-to documentation adequate to support LRIP	
			Test Readiness Review (TRR)	Design maturity sufficient to begin testing	• Qualification testing of components is complete • Test flow/sequence – ensure testing confirms workmanship and quality	
			System Verification Review (SVR)	Production-representative system complies with performance specification	• Concurrent with PRR	Team validates current MRLs
			Production Readiness Review (PRR)	System and manufacturing processes maturity sufficient to begin initial production	• Production risks reviewed, identified, and mitigated • Key manufacturing factors that affect component cost, performance, & reliability have been identified • Manufacturing process optimization plans are in place • Pilot manufacturing lines have been set up and tested. Ability to produce adequate yields has been validated • Suppliers of key materials and components have demonstrated a capability to support LRIP cost and schedule requirements • Production cost estimates meet goals • System design is stable enough to support LRIP schedules • System assessed against MRL 8	
					•	

Review Readiness Criteria (RRC) – Manufacturing (Top-Level) – 3 of 3

Milestone	Acquisition Phase	Sub-Phase	Review	Description of Review	Top-Level RRC	Verification/Certification Authority
C	Production & Deployment	LRIP	Operational Test Readiness Review (OTRR)	System maturity sufficient to begin IOT&E	• Production-representative articles used in testing • Production process capability satisfies design Key Characteristics (KCs)	DCMA or other cognizant government organization validates test articles were taken from the production line
		FRP/Deployment	Full Rate Production (FRP) DR	System IOT&E performance and manufacturing processes maturity sufficient to begin full-rate production	• Production processes are under statistical control • Sources for key materials and components are capable of meeting production requirements • LRIP actual costs and schedule performance support FRP cost goals and schedules • Design is stable enough to support rate production schedules	
	Operations & Support	Sustainment	In-Service Review (ISR)	Status check of measured performance in actual use	• Manufacturing improvements being made to respond to in-service issues • Effective process improvement continuing	

Review Readiness Criteria (RRC) – Manufacturing (Details) – 1 of 6

Milestone	Acquisition Phase	Sub-Phase	Review	Manufacturing Requirements: Description	Manufacturing Requirements: Measures	Status of Activities		Best Practices
A	Materiel Solution Analysis	N/A	ASR	• Technology Development Phase plans effectively address manufacturing maturity risks/needs and industrial base capability	• Cost Drivers • Trade Studies	• Technology Development Strategy/Plans complete • The manufacturing cost and schedule risk associated with key proposed system requirements alternatives are examined and the results are documented • Trade studies complete	Trade studies conducted and initiatives (such as technology initiatives) begun as needed	• MFG cost driver assessments effectively contribute to materiel solution decision making • Where proposed systems requirements imply high manufacturing cost or risk, tradeoffs are considered • Manufacturing and materials engineers participate in AoA, cost estimating and development of technology development plans • AoA Plan includes effective consideration of manufacturing implications of alternatives and involvement of MFG SMEs • Detailed manufacturing flow charts developed for key technologies • Technology Development Strategy and budget includes effective plans to bring key product technologies to a manufacturing readiness level of 6 or greater prior to MS B • Program plan developed in CR includes effective plans for manufacturing risk management and maturation of key industrial base capabilities and manufacturing technologies • Exit criteria for initial technology development spiral includes manufacturing maturity criteria • Technology Development Strategy includes plan to apply Lean practices and principles to entire weapon system enterprise(PEO, Program Office, Prime, OEMs, suppliers)
			ITR	• System Manufacturing (MFG) cost drivers quantified • Uncertainty range for MFG cost drivers reflected in program baseline • Enabling/critical technologies are at a minimum of MRL 4 • Plans and budget for Technology Development Phase sufficient to bring enabling/critical technologies to MRL 6	• Key MFG Requirements • Cost drivers • Cost ranges • MRL	• Key manufacturing requirements (materials, tolerances, specialized components) of competing concepts are identified and assessed against SOTA as well as cost/availability data and projections - associated cost drivers are identified • Cost drivers are quantified, a range of uncertainty is assigned to each cost driver – results were used in developing system cost estimates		

Review Readiness Criteria (RRC) – Manufacturing (Details) – 2 of 6

Milestone	Acquisition Phase	Sub-Phase	Review	Manufacturing Requirements: Description	Manufacturing Requirements: Measures	Status of Activities	Best Practices
B	Technology Development	N/A	SRR	• Initial assessment of industrial base capabilities complete • Adequate plans in place to address industrial base capability issues • System-level producibility analysis completed • Manufacturing cost and schedule risks for EMD effectively assessed • Enabling/critical technologies at a Manufacturing Readiness Level of 6 • EMD plans effectively address key manufacturing cost drivers, producibility issues and manufacturing maturity risks • Manufacturing plans and progress sufficient to support EMD	• IB capability issues/plans • Technology MRL levels • Producibility issues	• Initial industrial base capability analysis complete • Key manufacturing processes have been evaluated in a production-representative environment • Initial evaluation of Key Characteristics has been conducted and comparisons made to known process capability • EMD SEP addresses key manufacturing/producibility/industrial base issues • EMD cost and schedule risk assessment complete • Assessment of manufacturing readiness for enabling/critical technologies complete • Initial system level producibility analysis complete • Manufacturing facilities and plans in place to support EMD • Initial make/buy evaluations complete • Effective tooling and test equipment plans defined • Key special tooling and test equipment demonstrated in production representative environment • Special personnel skills in place or planned to support EMD • Long-lead requirements for EMD effectively addressed	• TD Phase investments in manufacturing maturity of enabling/critical technologies and industrial capabilities significantly reduce program manufacturing cost and schedule risk • Manufacturing SME's are an effective part of program cost and schedule risk assessments; producibility analyses, and creation of the EMD SEP • TD investments in advanced manufacturing technology reduce production cost estimates • EMD SEP and program budgeting support achieving MRL 8 prior to completion of EMD • DoD ManTech Program and DPA Title III resources are used to help address manufacturing maturity and industrial base capability issues • Value stream mapping at prime, OEMs and tier suppliers has identified key issues and opportunities for cycle time and cost reduction – target future state defined, action plans in place and being executed • Demonstrated yields and rate capabilities of key processes support the inclusion of essential technologies or design features in system design • EMD plans include Lean practices applied to entire weapon system enterprise

Review Readiness Criteria (RRC) – Manufacturing (Details) – 3 of 6

Milestone	Acquisition Phase	Sub-Phase	Review	Manufacturing Requirements: Description	Manufacturing Requirements: Measures	Status of Activities		Best Practices
	Engineering & Manufacturing Development	Integrated System Design	SFR	• Manufacturing schedules for EMD are executable within approved budget • Manufacturing-related skills and staffing are adequate to support EMD efforts • Manufacturing risks known and manageable for EMD	• Schedule risk • Manning data • Manufacturing risk levels	• SEP has been updated to reflect updated knowledge of key manufacturing/producibility/industrial base issues • Progress in executing manufacturing, tooling, test equipment, facilities, staffing plans has been assessed and is adequate to support EMD. Plans have been updated to reflect current knowledge • Manufacturing EMD schedule assessed to be executable within the approved program budget • Manufacturing schedule and cost estimates have been updated • Manufacturing risk assessments have been updated	Trade studies conducted and initiatives (such as technology initiatives) begun as needed	• Manufacturing technology efforts for cost reduction are adequately funded and underway • Lean opportunities identified by Value Stream Analyses actively pursued throughout weapon system enterprise
			PDR	• Second Industrial Capability Assessment complete – Effective plans in place/actions underway to put adequate industrial base capability in place to support program requirements • System assessed against MRL 6 • Producibility issues have been addressed sufficiently to proceed to detailed design	• Industrial base capability issues and risks • Manufacturing readiness levels/risks • Process yield • Process capability	• SEP has been updated to reflect updated knowledge of key manufacturing/producibility/industrial base issues • Initial producibility trade studies complete – results incorporated into design and/or manufacturing plans -- additional producibility efforts underway • Initial System-wide Manufacturing Readiness Assessment complete • Yields and process capability demonstrated in production representative environment for processing of key components		• Design for Manufacturing and Assembly (DFMA) applied to all assemblies where tolerances are a potential issue • Key OEMs and suppliers have meaningful role in system design process • Manufacturing processes under statistical process control • Lean opportunities identified by Value Stream Analyses actively pursued throughout weapon system enterprise

Review Readiness Criteria (RRC) – Manufacturing (Details) – 4 of 6

Milestone	Acquisition Phase	Sub-Phase	Review	Manufacturing Requirements: Description	Manufacturing Requirements: Measures	Status of Activities	Best Practices
	Engineering & Manufacturing Development	System Integration	PDR			• Specialized skill requirements have been identified • SEP has been updated to reflect updated knowledge of key manufacturing/producibility/industrial base issues • Progress in executing manufacturing, tooling, test equipment, facilities, staffing plans has been assessed and is adequate to support EMD. Plans have been updated to reflect current knowledge • Manufacturing EMD schedule assessed to be executable within the approved program budget • Manufacturing schedule and cost estimates have been updated • Manufacturing risk assessments have been updated • Design drawing release status and plans support effective tooling, manufacturing and supply chain efforts	

Review Readiness Criteria (RRC) – Manufacturing (Details) – 5 of 6

Milestone	Acquisition Phase	Sub-Phase	Review	Manufacturing Requirements: Description	Manufacturing Requirements: Measures	Status of Activities	Best Practices
	Engineering & Manufacturing Development	Integrated System Design	CDR	• Second system-wide MRA complete, system assessed against MRL 7 • Critical process capabilities/plans support Design Key Characteristics • Quarterly production risk reviews commenced • Process control plans developed • Build-to documentation adequate to support LRIP	• Manufacturing Readiness Level • Process capability • Key design characteristics	• SEP has been updated to reflect updated knowledge of key manufacturing/producibility/industrial base issues • Process capability demonstrated on EMD articles in pilot line • Progress in executing manufacturing, tooling, test equipment, facilities, staffing plans has been assessed and is adequate to support remainder of EMD. Plans have been updated to reflect current knowledge • Manufacturing EMD schedule assessed to be executable within the approved program budget • Manufacturing schedule and cost estimates have been updated • Manufacturing risk assessments have been updated • Second system-wide MRA complete, system assessed against MRL 7 • Required manufacturing technology solutions demonstrated • Design drawing release status and plans support effective tooling, manufacturing and supply chain efforts	• Failure Modes and Effects Analyses performed for all critical manufacturing processes. Results guiding process improvement efforts • Statistical process control being applied at all levels of supply chain • Lean improvement activities actively pursued throughout weapon system enterprise
			TRR	• Components have passed qualification testing • All materials meet specification • Test flow/sequence—ensure testing confirms workmanship and quality		• Component and material qualification testing complete • Specifications in place for all materials	

Review Readiness Criteria (RRC) – Manufacturing (Details) – 6 of 6

Milestone	Acquisition Phase	Sub-Phase	Review	Manufacturing Requirements: Description	Manufacturing Requirements: Measures	Status of Activities		Best Practices
C	Engineering & Manufacturing Development	System Capability and Manufacturing Process Demonstration.	SVR	• System producible within production budget		• PRR underway or completed • Production cost estimates updated to reflect EMD experience		
			PRR	• Production risks reviewed, identified, and mitigated ○ Key manufacturing factors that affect component cost, performance, & reliability have been identified. ○ Manufacturing process optimization plans are in place ○ Pilot manufacturing lines have been set up and tested. Ability to produce adequate yields has been validated. ○ Suppliers of key materials and components have demonstrated a capability to support LRIP cost and schedule requirements ○ Production cost estimates meet goals ○ System design is stable enough to support LRIP schedules • System assessed against MRL 8		• Production risks reviewed, identified, and mitigated ○ Key manufacturing factors that affect component reliability have been identified. ○ Manufacturing process optimization strategies have been described. ○ Pilot manufacturing lines have been set up and tested. Ability to produce adequate yields and reliability has been validated using EMD articles ○ Tooling and Special Test Equipment validated on EMD articles • Bill of Materials complete to support LRIP • Make/buy decisions complete to support LRIP • Special skills verified on EMD articles • Required manufacturing technology validated for LRIP • DFMA and producibility analysis activities complete • Sources available for all components and materials required for EMD		• Quarterly production risk reviews prior to PRR • Domestic sources available for all key components and materials • Multiple sources for many materials and components reduces manufacturing cost and schedule risk • All manufacturing processes under statistical process control and “in control” at Prime, OEMs and key subtier suppliers • Lean principles actively applied throughout weapon system enterprise

APPENDIX D.

SUMMARY OF MRL/MRA RESOURCES AVAILABLE THROUGH THE DEFENSE ACQUISITION UNIVERSITY WEBSITE

Finding the right web location:

Either go to http://www.dodmrl.com and click on the DAU link, or go directly to https://acc.dau.mil/CommunityBrowser.aspx?id=18231 .

Key Resources that are accessible include:

- Latest MRL Definitions
- Tutorial – A 1-hour tutorial on the development and use of Manufacturing Readiness Levels to accomplish assessments
- Links to all of the GAO Reports that are referenced in the body of this report as well as excerpts from the reports citing lessons learned for specific weapons systems
- The DoD Technology Readiness Assessment Deskbook
- A Manufacturing Readiness Guide that provides background on the development of MRLs and guidance on their use
- The MRL ASSIST Tool – An automated web-based tool designed for use by program IPTs to capture and manage MRA data for their programs. Currently in the Beta Testing Stage, but available for unrestricted use.