U.S. Army Research, Development and Engineering Command

2015 NDIA TUTORIAL

Manufacturing Readiness Assessments of Technology Development Projects

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Agenda

- Definitions
- DoD Acquisition Framework and Funding
- MRL Implementation
- MRL's and TRL's
- Threads and Sub-Threads
- Outline of the ARDEC MANTECH MRA Process
- Example
- Summary

What is a Manufacturing Process?

The total set of activities and interfaces necessary to convert the product definition into an affordable product.

What is Manufacturing Readiness?

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

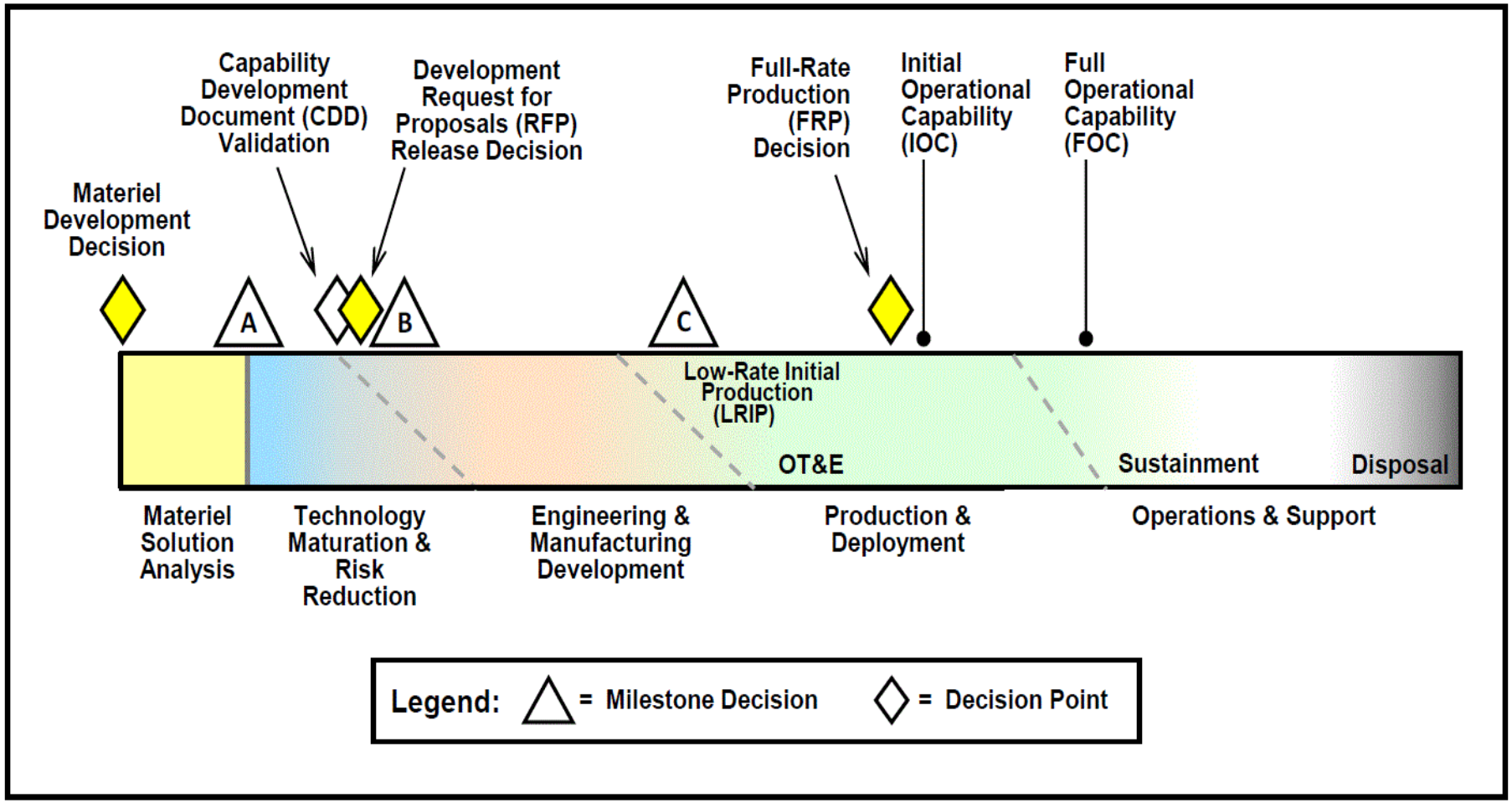
Relevant "–ilities"

- **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.
- **Producibility**—The relative ease of producing an item that meets engineering, quality and affordability requirements.

DoD Manufacturing Readiness Assessment (MRA)

- **Formal Risk Assessment with defined Focus Areas and DoD standard Criteria applicable throughout the DoD Acquisition Life Cycle.**
- Begins before and during the Development Phase of Systems, continues through the Production Phase and continues after a System has been fielded into the Sustainment Phase.
- Assesses the ability to transition manufacturing technology smoothly and efficiently from the Materiel Developers (RDEC's) onto the factory floor and into the field.

DoD Acquisition Life Cycle Model



Source: DoD Instruction 5000.02 – Operation of the Defense Acquisition System (7 Jan 2015)

Overview of Requirements for MRAs & MRLs

- **Law:**
  - Public Law 111–383; 124 Stat. 4264; 10 U.S.C. 2430:
    - *"Require the use of manufacturing readiness levels or other manufacturing readiness standards as a basis for measuring, assessing, reporting, and communicating manufacturing readiness and risk on **major defense acquisition programs** throughout the DoD"*
- **DoD:**
  - DoD Instruction 5000.02 (7 Jan 2015):
    - *"Program Manager will ensure manufacturing and producibility risks are identified and managed throughout the program's life cycle"*
- **Army:**
  - MRLs are required for Army MANTECH projects

US Army MANTECH (Manufacturing Technology)

- Supports reduction in production risks and manufacturing costs throughout the weapons system life cycle.
- The Program process is structured to fund projects that are deemed high priority for the Army.
- The Program supports process prototyping and pilot demonstration to develop or modify manufacturing technologies for the Army's use. It does not acquire off-the-shelf capital equipment unless it is a minor portion of the investment and is required to establish the first-case application integral to the ManTech project.
- Program Manager (PM) or organization responsible for transition and implementation must demonstrate a robust Acquisition Strategy that includes a realistic plan to transition and implement the technology in the industrial base.

Army Funding for Technology Development (RDTE,A)

S & T

- 6.1 (**Basic Research**) Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind (e.g, SBIR, ILIR).
- 6.2 (**Applied Research**) Applied research is systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods.
- 6.3 (**Advanced Technology Development**) Development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment. ATD includes concept and technology demonstrations of components and subsystems or system models. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use.

- ***6.7 (Operational System Development)*** *Development efforts to upgrade systems that have been fielded or have received approval for full rate production and anticipate production funding in the current or subsequent fiscal year (e.g., MANTECH) .*

MRL Implementation Guide Basic Research (6.1)

"In this early stage MRLs should only be used to obtain knowledge that would be useful to leadership to make informed decisions on which future manufacturing risk areas or technologies they may wish to address when proceeding into the Applied Research phase or to define manufacturing areas where more basic research needs to be done."

- Draft DoD MRL Implementation Guide

MRL Implementation Guide Applied Research (6.2)

- Use MRLs (1-4) to assess the manufacturing feasibility of the Basic Research results and provide leadership with knowledge of potential manufacturing shortfalls that should be addressed in the future development.
- Assess the application of the manufacturing capabilities, capacities, or materials needed to meet specific needs.

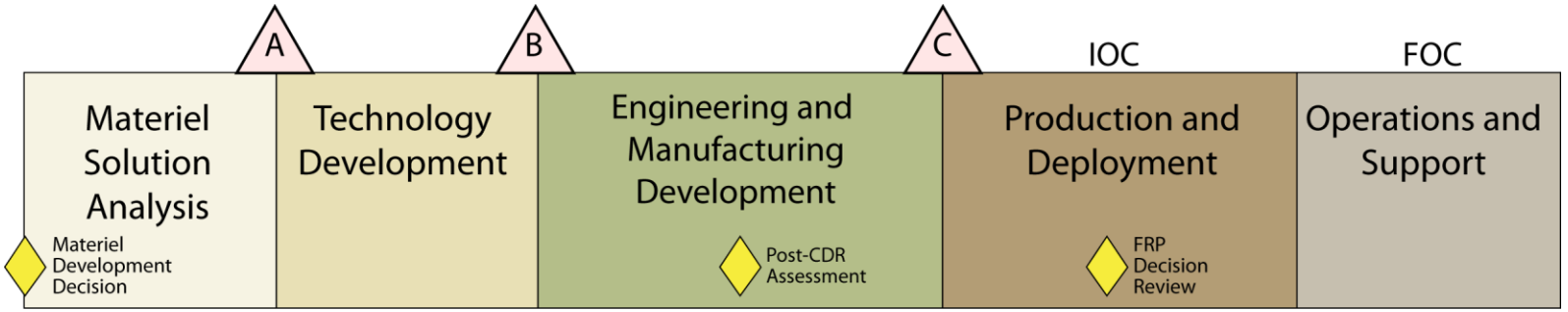
MRL Implementation Guide
Adv. Technology Development (6.3)

- Begin addressing manufacturing maturity of Prototypes being transitioned to acquisition.
- Determine the manufacturing risks before transitioning from ATD into EMD.
- Ensure that cost goals reflect manufacturing cost considerations and capabilities.
- Provide the PM with an understanding of the manufacturing maturity so they have a full understanding of the risk they assume by proceeding to the next phase

MRLs vs. TRLs

- **What is the difference between MRLs and TRLs?**
  - TRLs are a metric used to assess the maturity of, and the risk associated with, evolving technologies.
  - MRLs are a metric used to assess manufacturing readiness and producibility. MRLs provide decision makers (at all levels) with a common understanding of the relative maturity, identification and mitigation of manufacturing risks associated with manufacturing technologies, products, and processes.
- **TRLs & MRLs are complementary, but their "scores" may not be directly linked**
  - A Critical Technology Element (CTE) might be very mature yet the manufacturing processes required to produce it may be immature.
- **TRLs by themselves leave major transition questions unanswered:**
  - Is the technology producible? – What will these cost in production?
  - Can these be made in a production environment?
  - Are key materials and components available?

Technology and Manufacturing Readiness



TRLs 1-3 Analytical/ Experimental Critical Function/ Characteristic Proof of Concept	**TRL 4** Component And/or Breadboard Validation In a Laboratory Environment	**TRL 5** Component And/or Breadboard Validation In a Relevant Environment	**TRL 6** System/ Subsystem Model or Prototype Demonstrated In a Relevant Environment	**TRL 7** System Prototype Demonstrated In an Operational Environment		**TRL 8** Actual System Completed Qualified Through Test and Demonstration	**TRL 9** Actual System "Mission Proven" Through Successful Operations	**Technology Readiness Levels Defense Acquisition Guidebook Paragraph 10.5.2**
MRLs 1-3 Manufacturing Feasibility Assessed. Concepts identifed/ developed	**MRL 4** Capability to produce Technology In Lab Environment	**MRL 5** Capability to Produce Prototype Components In Production Relevant Environment	**MRL 6** Capability to Produce System/ Subsystem Prototypes in Production Relevant Environment	**MRL 7** Capability to Produce Systems, Subsystems Or Components in a Production Representative Environment	**MRL 8** Pilot Line Capability Demonstrated. Ready for LRIP	**MRL 9** Low Rate Production Demonstrated. Capability In Place for FRP	**MRL 10** Full Rate Production Demonstrated. Lean Production Practices In Place	**Manufacturing Readiness Levels** **Draft MRA Deskbook Oct 2012**

Section 2366b of Title 10, United States Code, requires certification that: the technology in a MDAP has been demonstrated in a relevant environment to enter Milestone B. (TRL 6)

MRL Definitions

- **MRL 1:** Basic Manufacturing Implications Identified
- **MRL 2:** Manufacturing Concepts Identified
- **MRL 3:** Manufacturing Proof of Concept Developed
- **MRL 4:** Capability to produce the technology in a laboratory environment
- **MRL 5:** Capability to produce **prototype components** in a **production relevant environment**
- **MRL 6:** Capability to produce a **prototype system or subsystem** in a **production relevant environment**
- **MRL 7:** Capability to produce systems, subsystems, or components in a **production representative environment**
- **MRL 8: Pilot line** capability demonstrated; Ready to begin Low Rate Initial Production
- **MRL 9:** Low rate production demonstrated; Capability in place to begin Full Rate Production
- **MRL 10:** Full Rate Production demonstrated and lean production practices in place

Production Relevant Environment (MRL 5 & MRL 6)

An environment with some shop floor production realism present (such as facilities, personnel, tooling, processes, materials etc.). There should be minimum reliance on laboratory resources during this phase. Demonstration in a production relevant environment implies that manufacturer(s) must demonstrate their ability to meet the cost, schedule, and performance requirements of the EMD Phase based on their production of prototypes. The demonstration must provide the program with confidence that these targets will be achieved. Furthermore, there must be an indication of how the manufacturer(s) intend to achieve the requirements in a production representative and pilot environments.

Production Representative Environment (MRL 7)

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

Pilot Line Environment (MRL 8)

An environment that incorporates all of the key production realism elements (equipment, personnel skill levels, facilities, materials, components, work instructions, processes, tooling, cleanliness, lighting etc.) required to manufacture production configuration items, subsystems or systems that meet design requirements in low rate production. To the maximum extent practical, the pilot line should utilize full rate production processes.

A Pilot Line normally represents the production line on which LRIP quantities will be manufactured

MRA's and MRLs

- **Manufacturing Readiness Assessment (MRA):**
  - The generic name for an event or process to identify and manage manufacturing risk.

- **Manufacturing Readiness Level:**
  - A MRA tool used to identify, quantify, and manage the manufacturing maturity and risk of a product or process.
  - Has objective criteria for all 10 levels across 9 major categories (Threads) and 22 minor categories (Sub-threads)
  - **MRL criteria adds "objectivity" to an otherwise subjective MRA**
    - Provides a universal basis of understanding for what each score means

Nine MRL Evaluation Criteria ("Threads")

- Technology and Industrial Base
- Design
- Cost and Funding
- Materials
- Process Capability and Control
- Quality Management
- Manufacturing Personnel
- Facilities
- Manufacturing Management

"Threads" & "Sub-Threads" (1)

A. Technology and Industrial Base

- Analyzes 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)
- A.1: **Industrial Base** (19 Questions through MRL10)
- A.2: **Manufacturing Technology Development** (12 Questions)

"Threads" & "Sub-Threads" (2)

B. **Design**

- Analyzes the maturity and stability of the evolving system design and any related impact on manufacturing readiness
- B.1: **Producibility** (21 Questions)
- B.2: **Design Maturity** (35 Questions)

"Threads" & "Sub-Threads" (3)

C. Cost and Funding

- Analyzes the adequacy of funding to achieve target manufacturing maturity levels. Examines the risk associated with reaching manufacturing cost targets
- C.1: **Production Cost Knowledge/Cost Modeling** (14 Questions)
- C.2: **Cost Analysis** (25 Questions)
- C.3: **Manufacturing Investment Budget** (20 Questions)

"Threads" & "Sub-Threads" (4)

D. **Materials**

- Analyzes the risks associated with materials (including basic/raw materials, components, semi-finished parts, and subassemblies)
- D.1: **Maturity** (16 Questions)
- D.2: **Availability** (21 Questions)
- D.3: **Supply Chain Management** (18 Questions)
- D.4: **Special Handling** (22 Questions)

"Threads" & "Sub-Threads" (5)

E. Process Capability and Control

- Analyzes the risks that the manufacturing processes are able to reflect the design intent (repeatability and affordability) of key characteristics
- E.1: **Modeling & Simulation** (16 Questions)
- E.2: **Manufacturing Process Maturity** (17 Questions)
- E.3: **Process Yields & Rates** (18 Questions)

"Threads" & "Sub-Threads" (6)

F. Quality Management

- Analyzes the risks and management efforts to control quality and foster continuous improvement at prime and suppliers
- F.1: **Quality Management** including Supplier Quality (16 Questions)
- F.2: **Product Quality** (17 Questions)
- F.3: **Supplier Quality Management** (17 Questions)

"Threads" & "Sub-Threads" (7)

G. Manufacturing Personnel

- Assesses the required skills, availability, and required number of personnel to support the manufacturing effort
- G.1: **Manufacturing Personnel** (22 Questions)

"Threads" & "Sub-Threads" (8)

H. **Facilities**

- Analyzes the capabilities and capacity of key manufacturing facilities (prime, subcontractor, supplier, vendor, and maintenance/repair)
- H.1: **Tooling/Special Test and Inspection Equipment (STE/SIE)** (15 Questions)
- H.2: **Facilities** (16 Questions)

"Threads" & "Sub-Threads" (9)

I. Manufacturing Management

- Analyzes the orchestration of all elements needed to translate the design into an integrated and fielded system (meeting program goals for affordability and availability)
- I.1: **Manufacturing Planning & Scheduling** (20 Questions)
- I.2: **Materials Planning** (15 Questions)

ARDEC MRA/MRL Implementation

- Apply DoD MRL Deskbook and provide a common language to assess:
  - the ***performance maturity of a MANTECH project and plans for its future maturation***
  - the level of performance risk in trying to transition the ManTech project into an armament system application
- Identify Contract Data Requirements for future ARDEC ManTech projects (e.g., SAE AS 6500 - Manufacturing Management Program)

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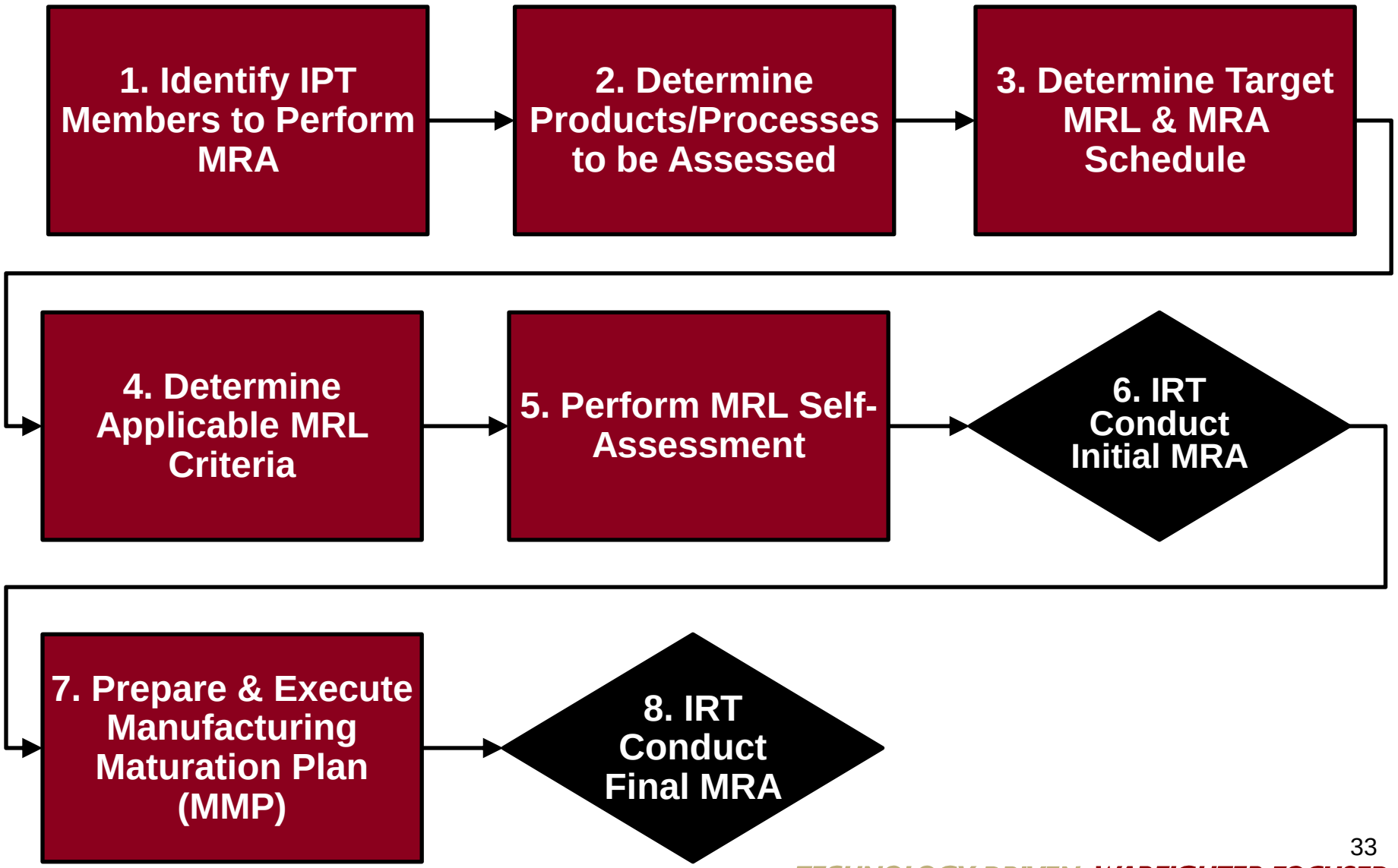
MRA's for ARDEC MANTECHs

- **The MRL criteria is the foundation for ARDEC MANTECH MRA's**
  - MDAP "requirements" can be scaled to fit Technology Development projects.
- **Some of the 9 Threads may not apply to ARDEC MANTECH projects, but all 9 Threads should be reviewed to ensure no manufacturing risks are missed**
  - If a thread does not apply to a project, then it is excluded from the assessment
  - If a thread is excluded from an assessment, "objective evidence" should be provided to justify the lack of a manufacturing risk
- **Aggregate/average/composite scores are not recommended**
- **TRLs & MRLs are complementary, but their "scores" should not be directly linked**
  - A Critical Technology Element might be very mature yet the mfg. processes needed to produce it may be very immature (or vice versa)
- **The MRL criteria adds "objectivity" to the MRA**
  - Provides the universal basis of understanding for what each score means

ARDEC MRA Process



Step 1: Identify IPT Members to Perform MRA

- Search Lessons Learned repository to review and learn from previous MRA experiences
- Identify IPT members responsible for conducting the MRA (can be adjusted throughout the MRA process)
- Notify IPT members of roles and responsibilities for conducting the MRA

Step 2: Determine Products & Processes to be Assessed

- Identify Products or Processes to be evaluated for manufacturing readiness considering:
  - Critical Technology Elements (CTEs)
  - Work Breakdown Structure/Bill of Materials
  - Uniqueness of the application
- Identify site visits, if required (Gemba Walk)
- Adjust IPT membership to reflect MRA Scope

Step 3: Determine Target MRL and MRA Schedule

- Based on Stakeholder Input, identify or infer the Target MRL for each product or process to be assessed
  - Determine the “Should Be” state
  - Document in Technology Transition Agreement (TTA) with Customer
- Update project schedule identifying major tasks and milestones leading to Final MRA

Step 4: Determine Applicable MRL Criteria

- Use the 9 Filtering Questions for each product and process to focus down from the 22 MRL Criteria Sub-Threads to a specific sub-set which address the unique challenges/risks of each product or process

- Create a MRL Questionnaire in the MRL Users Guide by filtering for the applicable MRL criteria for each identified product or process to be examined as a part the MRA (418 Total Questions across 22 Sub-Threads):

http://www.dodmrl.com/MRL_Users_Guide_V12.5.16.xls

MRL

Filtering Questions (1-3)

- **Materials**: Are there materials which have not been demonstrated in similar products or manufacturing processes?
- **Cost**: Is this item a driver that significantly impacts life-cycle cost (development, unit, or operations and support costs)? Is the technology new with high cost uncertainty?
- **Design**: Is the item design novel or does it contain nonstandard dimensions or tolerances or arrangements?

Filtering Questions 4-6

- **Manufacturing Process:** Will the item require the use of manufacturing technology, processes, inspection, or capabilities that are unproven in the current environment?
- **Quality**: Does the item have historical/anticipated yield or quality issues?
- **Schedule**: Does this item have lead time issues or does it significantly impact schedule?

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Filtering Questions 7-9

- **Facilities**: Does this item require a new manufacturing facility or scale up of existing facilities (i.e., new capability or capacity)?
- **Supply Chain Management**: Does the item have anticipated or historical sub-tier supplier problems (e.g., cost, quality, delivery)?
- **Industrial Base**: Does the item have an industrial base footprint with critical shortfalls or is this a critical item manufactured by a sole or foreign source?

Step 5: Perform MRL Self-Assessment

- Complete the MRL Questionnaire for each identified product or process in the MRA
- Determine/collect the documentation/objective evidence/tangible evidence required to conduct and support the Self-Assessment
  - Determine the “As Is” state
- Prepare the MRA Self-Assessment using the identified documentation/test data and correlating this information with the applicable MRL requirements and scores
- Develop the Manufacturing Maturation Plan (MMP), budget, & schedule to achieve the next higher MRL

MMP Contents

- Problem Statement
- Solution Options
- Maturation Plan identifying Budget and Schedule
- Key activities for the preferred approach
- Preparations for using an alternative approach
- Latest time that an alternative approach can be chosen
- Status of funding to execute the manufacturing plan
- Specific actions to be taken and by whom
- Prototypes or test articles to be built
- Tests to be conducted
- Threshold performance to be met
- MRL to be achieved and when it will be achieved
- Current Status

Step 6: Conduct Initial MRA Review

- Form Independent Review Team (IRT) of Management-level SME's
- Each IRT member reviews MRA Self-Assessment, objective evidence and MMP and provides independent assessments to IRT Chairperson
- Chairperson integrates individual IRT assessments, reconciles discrepancies with IRT, as required
- Conduct the Review and publish IRT independent assessment
  - The IRT must reach consensus on all issues
- Assign and close-out any Action Items
- Update MMP

Step 7: Execute MMP

- Execute maturation activities IAW the Manufacturing Maturation Plan
  - Conduct site visits
  - Collect objective evidence
  - Update/create MMPs as necessary
  - Adjust Scope as necessary
- Update MRL Self-Assessment
- Prepare for and conduct Interim MRA Reviews (if required)
- Prepare for Final MRA Review

Step 8: Conduct Final Independent MRA Review

- Convene IRT members for Review
- Assemble, organize, and distribute supporting artifacts and information to the IRT to review in advance of the Independent MRA Review
  - IRT reviews team assessment, recommendation and objective evidence
- Conduct the review and determine actual MRLs
- Prepare for transition to Customer or continue executing the MMP

MRA Review Approach

- **Concentrate on the targeted MRL**
  - If target MRL criteria is unsatisfied, review lower level questions to determine actual MRL and effort required to meet target MRL
- **Confirm that all pertinent MRL criteria was addressed**
- **Verify (hands-on/eyes-on) that all objective evidence meets the MRL criteria**
  - Seek tangible proof that the agreed upon interpretation of a particular MRL sub-thread definition has been satisfied; proof that manufacturing risk has been mitigated and/or maturity has increased
- **Update Manufacturing Maturation Plans (MMPs) if target MRL has not been achieved**

It's Not About The Score

- **Do not focus on the MRL number like a Report Card.**
- **Use MRL's and the MRA process to identify and mitigate manufacturing RISK.**
- **Use the MMP to address residual manufacturing RISK.**

Example - F2. Product Quality

Sub-Thread	MRL	Question
F.2 – Product Quality	4	Has a product inspection and acceptance testing strategy been identified as part of the Acquisition Strategy?
	4	Has a product inspection and acceptance testing strategy been included in the Systems Engineering Plan (SEP)?
	5	Have roles and responsibilities been identified for acceptance test procedures, in-process and final inspections?
	5	Have statistical process controls been identified for prototype units?
	6	Has a Key Characteristic management approach been defined?
	6	Have initial requirements been identified for acceptance test procedures and in-process and final inspection requirements for EMD units?
	6	Have appropriate inspection and acceptance test procedures been identified for prototype units?

Example - Questionnaire Scoring

Question	ANS	MRL	Comments
Has a product inspection and acceptance testing strategy been identified as part of the Technology Development Strategy?	**Yes**	4	Identified in the TDS
Has a product inspection and acceptance testing strategy been included in the Systems Engineering Plan (SEP)?	**N/A**	4	Product Inspection and Acceptance Testing strategy is not identified in SEP; they are identfied in PRF and TEMP
Have roles and responsibilities been identified for acceptance test procedures, in-process and final inspections?	**No**	5	
Have statistical process controls been identified for prototype units?	**No**	5	
Has a Key Characteristic management approach been defined?	**No**	6	
Have initial requirements been identified for acceptance test procedures and in-process and final inspection requirements for EMD units?	**No**	6	
Have appropriate inspection and acceptance test procedures been identified for prototype units?	**No**	6	

Sample Graphic Of MRA Scores

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					A		B		C		
ManTech	MRA Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
HE Loading											
	A.2 Manufacturing Technology Development										
	C.2 Cost Analysis										
	E.2 Manufacturing Process Maturity										
	E.3 Process Yields & Rates										
	F.2 Product Quality										
	H.1 Tooling/STE/SIE										

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Basic Manufacturing Implications Identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Manufacturing Processes In Lab Environment	Components In Production Relevant Environment	System or Subsystem In Production Relevant Environment	System or Subsystem In Production Representative Environment	Pilot Line Demonstrated Ready for LRIP	LRIP Demonstrated Ready for FRP	FRP Demonstrated Lean Production Practices in Place

Summary

- ARDEC Has Implemented a New MRA Process for MRL Assessments of Army MANTECH Projects:
  - Aligned with the DoD Acquisition Framework and Conforms with DoD Instruction 5000.02.
  - Based on Best Practices Described in the DoD Manufacturing Readiness Level (MRL) Deskbook.
- MRL Metrics Help Acquistion Program Managers Manage Manufacturing Capability and Readiness Risks
  - Goes Hand-In-Hand With Use of TRLs to Manage Technology Risks

Backup

(The following MRL Deskbook Criteria charts are hyperlinked in the Tutorial)

MRL Threads & Criteria

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DoD Manufacturing Readiness Levels (MRLs)

Acquisition Phase		Pre Materiel Solution Analysis (Pre MSA)			Materiel Solution Analysis (MSA)	Technology Maturation and Risk Reduction (TMRR)		Engineering & Mfg Development (EMD)		Low-Rate Initial Production (LRIP)	Full-Rate Production (FRP)
Technical Reviews					ASR (A)	SRR/SFR	PDR (B)	CDR	PRR/SVR (C)	PCA (FRP)	
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
	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 or Higher.	Should be assessed at TRL 8 or Higher.	Should be assessed at TRL 9.
A - Technology and Industrial Base	A.1 - Industrial base			Potential sources identified to address technology needs. Understand state of the art.	Industrial base capabilities surveyed and known gaps/risks identified for preferred concept, key technologies, components, and/or key processes.	Industrial base capabilities assessment initiated to identify potential manufacturing sources. Sole/single/ foreign source vendors and vendors of technologies with potential obsolescence issues have been identified and planning has begun to minimize risks.	Industrial base capabilities assessment for MS B has been completed. Industrial capability in place to support manufacturing of development articles. Plans to minimize sole/ foreign sources and obsolescence issues complete. Need for sole/single/foreign sources justified. Potential alternative sources identified.	Industrial capability to support production has been analyzed. Sole/single/foreign sources stability and obsolescence issues are assessed/monitored. Developing potential alternate sources as necessary.	Industrial base capability assessment 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 modifications, upgrades, surge and other potential manufacturing requirements.
	A.2 - 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, if applicable.	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.	Primary manufacturing technology efforts concluding, and some improvement efforts continuing. Required manufacturing technology solutions validated on a pilot line.	Manufacturing technology process improvements efforts initiated for FRP.	Manufacturing technology continuous process improvements ongoing.
B - Design	B.1 - Producibility Program			Relevant materials/processes evaluated for manufacturability using experiments/models.	Initial producibility and manufacturability assessment of preferred systems concepts completed. Results considered in selection of preferred design concepts and reflected in Technology Development Strategy key components/ technologies.	Producibility and manufacturability assessments of key technologies and components initiated as appropriate. Ongoing design trades consider manufacturing processes and industrial base capability constraints. Manufacturing processes assessed for capability to test and verify in production, and influence on Operations & Support.	Producibility assessments and producibility trade studies (performance vs. producibility) of key technologies/components completed. Results used to shape Acquisition Strategy, Systems Engineering Plan (SEP), Manufacturing and Producibility plans, and planning for EMD or technology insertion programs. Preliminary design choices assessed against manufacturing processes and industrial base capability constraints. Producibility enhancement efforts (e.g. Design For Mfg, Assembly, Etc. (DFX)) initiated.	Detailed producibility trade studies using knowledge of key design characteristics and related manufacturing process capability completed. Producibility enhancement efforts (e.g. DFX) ongoing for optimized integrated system. Manufacturing processes re-assessed as needed for capability to test and verify potential influence on Operations & Support.	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.	Design producibility improvements demonstrated in FRP. Process producibility improvements ongoing. All modifications, upgrades, Diminishing Mfg Sources & Material Shortages (DMSMS) and other changes assessed for producibility.
	B.2 - Design Maturity	Manufacturing research 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 lifecycle and technical requirements evaluated.	SEP 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 potential Key Performance Parameters (KPPs) identified for preferred systems concept. System characteristics and measures to support required capabilities identified. Form, fit, and function constraints identified and manufacturing capabilities identified for preferred systems concepts.	Lower level performance requirements sufficient to proceed to preliminary design. All enabling/critical technologies and components identified and considers the product lifecycle. Evaluation of design Key Characteristics (KC) initiated. Product data required for prototype component manufacturing released.	System allocated baseline established. Product requirements and features are well enough defined to support preliminary design review. Product data essential for subsystem/system prototyping has been released, and all enabling/critical component have been prototyped. Preliminary design KCs have been identified and mitigation plans in development.	Product design and features are well enough defined to support critical design review, even though design change traffic may be significant. All product data essential for component manufacturing has been released. Potential KC risk issues have been identified and mitigation plan is in place.	Detailed design of product features and interfaces is complete. All product data essential for system manufacturing has been released. Design change traffic is limited. All KCs are controlled in LRIP to appropriate quality levels.	Major product design features and configuration are stable. System design has been validated through operational testing of LRIP items. Physical Configuration Audit (PCA) or equivalent complete as necessary. Design change traffic is limited. All KCs are controlled in LRIP to appropriate quality levels.	Product design is stable. Design changes are few and generally limited to those required for continuous improvement or reaction to obsolescence. All KCs are controlled in FRP to appropriate quality levels.
C - Cost & Funding	C.1 - Production Cost Knowledge (Cost modeling)		Cost model approach defined.	Initial cost targets and risks identified. High level process chart model developed. Technology cost models developed for new process steps and materials based on experiments.	Manufacturing, material and special processes cost drivers identified. Detailed process chart cost models driven by process variables. Cost driver uncertainty quantified.	Prototype components produced in a production relevant environment, or simulations drive end-to-end cost models. Cost model includes materials, labor, equipment, tooling/Special Test Equipment (STE), setup, yield/scrap/rework, Work In Progress (WIP), and capability/capacity constraints.	Cost model updated with design requirements, material specifications, tolerances, integrated master schedule, results of system/subsystem simulations and production relevant prototype demonstrations.	Cost model updated with the results of systems/sub-systems produced in a production representative environment, production plant layout and design, and obsolescence solutions.	Cost models updated with results of pilot line build.	LRIP cost model updated with result of LRIP build.	Cost model validated against actual FRP cost.
	C.2 - 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).	Producibility cost risks assessed. Initial cost models support Analysis of Alternatives (AoA) and Alternative Systems Review (ASR).	Costs analyzed using prototype component actuals to ensure target costs are achievable. Decisions regarding design choices, make/buy, capacity, process capability, sources, quality, key characteristics, yield/rate, and variability influenced by cost models.	Costs analyzed using prototype system/sub-system actuals to ensure target costs are achievable. Allocate cost targets to subsystems. Cost reduction and avoidance strategies developed. Provide manufacturing cost drivers for "Should-Cost" models.	Manufacturing costs rolled up to system/sub-system level and tracked against targets. Detailed trade studies and engineering change requests supported by cost estimates. Cost reduction and avoidance strategies underway. Update manufacturing cost drivers for "Should-Cost" models.	Costs analyzed using pilot line actuals to ensure target costs are achievable. Manufacturing cost analysis supports proposed changes to requirements or configuration. Cost reduction initiatives ongoing. Update manufacturing cost drivers for "Should-Cost" models.	LRIP cost goals met and learning curve analyzed with actual data. Cost reduction initiatives ongoing. Touch labor efficiency analyzed to meet production rates and elements of inefficiency are identified with plans in place for reduction.	FRP cost goals met. Cost reduction initiatives ongoing.
	C.3 - Manufacturing Investment Budget	Potential investments identified.	Program/projects have reasonable budget estimates for reaching MRL 3 through experiment.	Program/projects have reasonable budget estimates for reaching MRL 4 by MS A.	Manufacturing technology initiatives identified to reduce costs. Program has reasonable budget estimate for reaching MRL 6 by MS B. Estimate includes capital investment for production-relevant equipment. All outstanding MRL 4 risk areas understood with approved mitigation plans in place.	Program has updated budget estimate for reaching MRL 6 by MS B. All outstanding MRL 5 risk areas understood with approved mitigation plans in place.	Program has reasonable budget estimate for reaching MRL 8 by MS C. Estimate includes capital investment for production-representative equipment by CDR and pilot line equipment by MS C. All outstanding MRL 6 risk areas understood with approved mitigation plans in place.	Program has updated budget estimate for reaching MRL 8 by MS C. All outstanding MRL 7 risk areas understood with approved mitigation plans in place.	Program has reasonable budget estimate for reaching MRL 9 by the FRP decision point. Estimate includes investment for LRIP and FRP. All outstanding MRL 8 risk areas understood with approved mitigation plans in place.	Program has reasonable budget estimate for FRP. All outstanding MRL 9 risk areas understood with approved mitigation plans in place.	Production budgets sufficient for production at required rates and schedule to support funded program.
D - Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)	D.1 - Maturity	Material properties identified for research.	Material properties and characteristics predicted.	Material properties validated and assessed for basic manufacturability using experiments.	Projected materials have been produced in a laboratory environment.	Materials have been manufactured or produced in a prototype environment (may be in a similar application/program). Maturation efforts in place to address new material production risks for technology demonstration.	Material maturity verified through technology demonstration articles. Preliminary material specifications in place and material properties have been adequately characterized.	Material maturity sufficient for pilot line build. Material specifications approved.	Materials proven and validated during EMD as adequate to support LRIP. Material specification stable.	Material is controlled to specification in LRIP. Materials proven and validated as adequate to support FRP.	Material is controlled to specification in FRP.
	D.2 - Availability		Material availability assessed.	Material scale-up issues identified.	Projected lead times have been identified for all difficult to obtain, difficult to process, or hazardous materials. Quantities and lead times estimated.	Availability issues addressed for prototype build. Significant material risks identified for all materials. Planning has begun to address scale-up issues.	Availability issues addressed to meet EMD build. Long-lead items identified. Components assessed for future DMSMS risk.	Availability issues addressed to meet LRIP builds. Long lead procurement initiated. Identified and mitigated DMSMS mitigation strategies for components in place.	Availability issues pose no significant risk for LRIP. Long lead procurement initiated for LRIP. Availability issues addressed to meet FRP builds.	Availability issues pose no significant risk for FRP. Long lead procurement initiated for FRP.	Program is in FRP with no significant material availability issues.
	D.3 - Supply Chain Management			Initial assessment of potential supply chain capability.	Survey completed for potential supply chain sources.	Potential supply chain sources identified and evaluated as able to support prototype build.	Lifecycle Supply Chain requirements updated. Critical suppliers list updated. Supply chain plans in place (e.g. teaming agreements, etc.) supporting an EMD contract award.	Effective supply chain management processes defined, documented, and in place. Plan developed for predictive indicators. Assessment of critical first tier supply chain completed (e.g. capability, capacity, etc.).	Assessment of critical second and lower tier supply chain completed. Robust requirements flow down processes in place and verified. Validated supplier compliance with program requirements and changes. Plan for predictive indicators updated and to be used in production. Supply chain adequate to support LRIP.	Long term agreements in place where practical. Prime's supplier management metrics (including thresholds and goals) in place and used to manage risks. Predictive indicators to manage suppliers in place. Supply chain is stable and adequate to support FRP.	Supply chain proven and supports FRP requirements.
	D.4 - Special Handling (i.e., QFP, shelf life, security, NNEMAT, storage environment, etc.)		Initial evaluation of potential regulatory requirements and special handling concerns.	List of hazardous materials identified. Special handling procedures applied in the lab. Special handling concerns assessed.	List of hazardous materials updated. Special handling procedures applied in the lab. Special handling requirements identified.	Special handling procedures applied in production relevant environment. Special handling requirement gaps identified. New special handling processes demonstrated in lab environment.	Special handling procedures applied in production relevant environment. Plans to address special handling requirement gaps complete.	Special handling procedures applied in production representative environment. Special handling procedures developed and annotated on work instructions for pilot line.	Special handling procedures applied in pilot line environment. Special handling procedures demonstrated in EMD or Technology Insertion Programs. Special handling issues pose no significant risk for FRP.	Special handling procedures applied in LRIP environment. Special handling procedures demonstrated in LRIP. Special handling issues pose no significant risk for FRP.	Special handling procedures effectively implemented in FRP.

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MRL Threads & Criteria

U.S. ARMY RDECOM

DoD Manufacturing Readiness Levels (MRLs)												
Acquisition Phase		**Pre Materiel Solution Analysis (Pre MSA)**			**Materiel Solution Analysis (MSA)**	**Technology Maturation and Risk Reduction (TMRR)**		**Engineering & Mfg Development (EMD)**			**Low-Rate Initial Production (LRIP)**	**Full-Rate Production (FRP)**
Technical Reviews					ASR (A)	SRR/SFR	PDR (B)	CDR	PRR/SVR (C)		PCA (FRP)	
Thread	**Sub-Thread**	**MRL 1**	**MRL 2**	**MRL 3**	**MRL 4**	**MRL 5**	**MRL 6**	**MRL 7**	**MRL 8**		**MRL 9**	**MRL 10**
	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 or Higher		Should be assessed at TRL 8 or Higher	Should be assessed at TRL 9.
E - Process Capability & Control	E.1 - Modeling & Simulation (Product & Process)		Initial models developed, if applicable.	Identification of proposed manufacturing concepts or producibility needs based on high-level process flow chart models.	Production modeling/simulation approaches for process or product are identified.	Initial models/simulation (product or process) developed at the component level and used to determine constraints.	Initial models/simulation developed at the sub-system or system level, and used to determine system constraints.	Models/simulation used to determine system constraints and identify improvement opportunities.	Models/simulation verified by pilot line build. Results used to improve process and determine that LRIP requirements can be met.		Models/simulation verified by LRIP build. Results in management of LRIP, and determines that FRP requirements can be met.	Models/simulation models used as a tool to assist in management of FRP.
	E.2 - 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 for pilot line, LRIP and FRP.	Manufacturing processes demonstrated in production relevant environment. Begin collecting or estimating process capability data from prototype build and refine process capability requirements.	Manufacturing processes demonstrated in a production representative environment. Continue collecting or estimating process capability data and refine process capability requirements.	Manufacturing processes verified for LRIP on a pilot line. Process Capability data from pilot line meets target. Refine process capability requirements for LRIP and FRP based upon Pilot line data.		Manufacturing processes are stable, adequately controlled, capable, and have achieved program LRIP objectives. Variability experiments conducted to show FRP impact and potential for continuous improvement.	Manufacturing processes are stable, adequately controlled, capable, and have achieved program FRP objectives.
	E.3 - Process Yields and Rates			Initial estimates of yields and rates based on experiments or state of the art.	Yield and rates assessment on proposed/similar processes complete and applied within Analysis of Alternatives (AoA).	Target yields and rates established for pilot line, LRIP, and FRP. Yield and rate issues identified. Improvement plans developed/initiated.	Yields and rates from production relevant environment evaluated against targets and the results feed improvement plan.	Yields and rates from production representative environment evaluated against pilot line targets and the results feed improvement plans.	Pilot line targets achieved. Yields and rates required to begin LRIP refined using pilot line results. Improvement plans ongoing and updated.		LRIP yield and rate targets achieved. Yields and rates required to begin FRP refined using LRIP results. Yield improvements on-going.	FRP yield and rate targets achieved. Yield improvements on-going.
F - Quality Management	F.1 - Quality Management including Supplier Quality.				Quality strategy identified as part of the Technology Development Strategy and included in Systems Engineering Plan (SEP).	Quality strategy updated to reflect Key Characteristic identification activities.	Initial quality plan and quality management system is in place. Quality risks and metrics have been identified and improvement plans initiated.	Quality targets established. Quality Management System (QMS) elements (e.g., control of nonconforming material, corrective action, etc.) meet requirements of appropriate industry standards. Program-specific Quality Program Plan being developed.	Program-specific Quality Program Plan and Quality Manager established. Quality targets assessed against pilot line, results feed continuous quality improvements.		Quality targets verified on LRIP line. Continuous quality improvement on-going. Management review of Quality measures is conducted on regular basis and appropriate action is taken.	Quality targets verified on FRP line. Continuous quality improvement on-going. Statistical controls applied where appropriate.
	F.2 - Product Quality				Product inspection and acceptance testing strategy identified as part of the Technology Development Strategy and included in Systems Engineering Plan (SEP).	Roles and responsibilities identified for acceptance test procedures, in-process and final inspections, and statistical process controls for prototype units.	Key Characteristic management approach defined. Initial requirements identified for acceptance test procedures and in-process and final inspection requirements for EMD units. Appropriate inspection and acceptance test procedures identified for prototype units.	Quality data from the production representative environment collected and analyzed and results used to shape improvement plans. Control plans completed for management of Key Characteristics. Test and Inspection plans being developed for EMD units.	Key Characteristics managed. Measurement procedures and controls in place (e.g. SPC, FRACAS, audits, customer satisfaction, etc.). Pilot line data meets capability requirements for all Key Characteristics. Test and Inspection plans complete and validated for production units.		Data from LRIP demonstrates production processes for all Key Characteristics and other manufacturing processes critical to quality are capable and under control for FRP.	Quality of Key Characteristics controlled at rate, data reflects only rare and unrepeated quality issues related to manufacturing processes. Results achieve targeted statistical level on all Key Characteristics. Results reflect continuous improvement.
	F.3 - Supplier Quality Management				Potential supplier base quality capabilities and risks identified, including subtier supplier quality management.	Supply base quality capabilities and risks identified, including subtier supplier quality management.	Supply base quality improvement initiatives identified addressing supplier Quality Management System shortfalls, including subtier supplier quality management.	Key supplier Quality Managemetn Systems meet appropriate industry standards. Supplier quality data from production representative units collected and analyzed. Strategy for audits of critical supplier processes outlined.	Supplier program-specific Quality Management Systems are adequate. Supplier products have completed qualification testing and first article inspection. Acceptance testing of supplier products is adequate to begin LRIP. Plan for subcontractor process audits in place and implemented by prime contractor.		Supplier management of quality of Key Characteristics and other critical manufacturing processes demonstrates capability and control for FRP. Acceptance testing of supplier products reflects control of quality adequate to begin FRP. Subcontractor Quality Audits performed as necessary to ensure subcontractor specification compliance.	Supplier quality data reflects adequate management of key characteristics and control of critical manufacturing processes, including quality management down to subtier suppliers. Results achieve high statistical level (e.g. 6-sigma) on all critical dimensions. Subcontractor Quality Audits performed as necessary to ensure subcontractor specification compliance.
G - Mfg Workforce (Engineering & Production)	G.1 - Mfg Workforce (Engineering & Production)			New manufacturing skills identified.	Mfg. skill sets identified and production workforce requirements (technical and operational) evaluated as part of AoA. Determine availability of process development workforce for the Technology Development Phase.	Skill sets identified and plans developed to meet prototype and production needs. Special skills certification and training requirements established.	Mfg. workforce skills available for production in a relevant environment. Identify resources (quantities and skill sets) and develop initial plans to achieve requirements for pilot line and production.	Mfg. workforce resource requirements identified for pilot line. Plans developed to achieve pilot line requirements. Plans updated to achieve LRIP workforce requirements. Pilot line workforce trained in production representative environment.	Mfg. workforce resource requirements identified for LRIP. Plans developed to achieve LRIP requirements. Plans updated to achieve FRP workforce requirements. LRIP personnel trained on pilot line where possible.		LRIP personnel requirements met. Implement plan to achieve FRP workforce requirements.	FRP personnel requirements met. Production workforce skill sets maintained due to attrition of workforce.
H - Facilities	H.1 - Tooling / Special Test and Inspection Equipment (STE/SIE)				Tooling/Special Test Equipment (STE)/Special Inspection Equipment (SIE) requirements are considered as part of AoA.	Identify tooling and STE/SIE requirements and provide supporting rationale and schedule.	Prototype tooling and STE/SIE concepts demonstrated in production relevant environment. Production tooling and STE/SIE requirements developed.	Production tooling and STE/SIE design and development efforts underway. Mfg equipment maintenance strategy developed.	Tooling, test and inspection equipment proven on pilot line and additional requirements identified for LRIP. Mfg equipment maintenance demonstrated on pilot line.		All tooling, test and inspection equipment proven in LRIP and additional requirements identified for FRP. Mfg equipment maintenance schedule demonstrated.	Proven tooling, test and inspection equipment in place to support maximum FRP. Planned equipment maintenance schedule achieved.
	H.2 - Facilities			Specialized facility requirements/needs identified.	Availability of manufacturing facilities for prototype development and production evaluated as part of AoA.	Manufacturing facilities identified and plans developed to produce prototypes.	Manufacturing facilities identified and plans developed to produce pilot line build.	Manufacturing facilities identified and plans developed to produce LRIP build.	Pilot line facilities demonstrated. Mfg facilities adequate to begin LRIP. Plans in place to support transition to FRP. Workplace safety is adequate.		Mfg facilities in place and demonstrated in LRIP. Capacity plans adequate to support FRP.	Production facilities in place and capacity demonstrated to meet maximum FRP requirements.
I - Mfg Management	I.1 - Mfg Planning & Scheduling				Mfg. strategy developed and integrated with acquisition strategy. Prototype schedule risk mitigation efforts incorporated into Technology Development Strategy (TDS).	Mfg. strategy refined based upon preferred concept. Prototype schedule risk mitigation efforts initiated.	Initial mfg. approach developed. All system design related mfg events included in Integrated Master Plan/Schedule (IMP/S). Mfg risk mitigation approach for pilot line or technology insertion programs defined.	Initial mfg. plan developed. Mfg planning included in IMP/S. Mfg risks integrated into risk mitigation plans. Initial work instructions developed. Effective production control system in place to support pilot line.	Mfg. plan updated for LRIP. All key manufacturing risks are identified and assessed with approved mitigation plans in place. Work instructions finalized. Effective production control system in place to support LRIP.		Mfg. plan updated for FRP. All manufacturing risks tracked and mitigated. Effective production control system in place to support FRP.	All manufacturing risks mitigated.
	I.2 - Materials Planning				Technology development article component list developed with associated lead time estimates.	Technology development part list maturing. Make/buy evaluations begin, and include production considerations reflecting Pilot line, LRIP, and FRP needs. Lead times and other risks identified.	Most material decisions complete (make/buy), material risks identified and mitigation plans developed. Bill of Materials (BOM) initiated.	Make/Buy decisions and BOM complete for pilot line build. Material planning systems in place for pilot line build.	Make/Buy decisions and BOM complete to support LRIP. Material planning systems proven on pilot line for LRIP build.		Make/Buy decisions and BOM complete to support FRP. Material planning systems proven in LRIP and sufficient for FRP.	Material planning systems validated on FRP build.