

# Manufacturing Readiness Level (MRL)

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*Kestävää kasvua ja työtä -ohjelma*



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## MRL vs. TRL

- Manufacturing readiness and technology readiness go hand-in-hand
- Manufacturing processes will not be able to mature until the product technology and product designs are stable.
- MRLs include a numbering system roughly similar to TRLs for synergy and ease of understanding and use.



# Manufacturing Readiness Levels

- Scope
  - Technology, component, manufacturing process, system, sub-system
- Support
  - Providing a common metric and vocabulary for assessing
  - Defining current level of manufacturing maturity
  - Identify maturity shortfalls and associated costs and risks
  - Provide the basis for manufacturing maturation and risk management
- Origin
  - United States Department of Defense (DOD)  
<http://www.dodmrl.com/>



# Why MRL's?

- Experiences

- Systems cost far more and take much longer to build than estimated
- Unit cost increases are common after production begins
- Inattention to manufacturing during planning and design
- Poor supplier management
- Deficit in manufacturing knowledge among the acquisition organisation
- Programs have not identified manufacturing risks early in development, risks carried into production where they are more significant problems

<http://www.dodmrl.com/>



# Manufacturing threads considered in MRL (threads of developing the acquisition strategy)

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

<http://www.dodmrl.com/>



# Manufacturing threads considered in MRL (threads of developing the acquisition strategy)

- Technology and industrial base capabilities
  - Industrial base issues
  - Manufacturing technology development
- Design
  - Producibility
  - Maturity
- Cost and funding
  - Production cost knowledge (cost modeling)
  - Cost analysis
  - Manufacturing investment budget



# Manufacturing threads considered in MRL (threads of developing the acquisition strategy)

- Materials
  - Maturity
  - Availability
  - Supply chain management
  - Special Handling
- Process capability and control
  - Modeling and simulation (product and process)
  - Manufacturing process maturity
  - Process yields and rates
- Quality management
  - Supplier quality



# Manufacturing threads considered in MRL (threads of developing the acquisition strategy)

- Manufacturing personnel
- Facilities
- Manufacturing management
  - Manufacturing planning and scheduling
  - Materials planning
  - Tooling / special test
  - Inspection equipment





# MRLs 1-10

- 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 (LRIP)**
- MRL 9: Low rate production demonstrated; capability in place to begin **Full Rate Production (FRP)**
- MRL 10: **Full Rate Production demonstrated** and **lean production practices in place**

<http://www.dodmrl.com/>



# MRLs 1-3

- MRL 1: **Basic Manufacturing Implications** Identified
  - Basic research related to manufacturing shortfalls and opportunities
- MRL 2: **Manufacturing Concepts** Identified
  - The application of new manufacturing concepts are described
  - Basic research is translated into solutions for broadly defined needs
  - Identification, paper studies and analysis of material and process approaches
  - Emerging understanding of manufacturing feasibility and risk
- MRL 3: **Manufacturing Proof of Concept** Developed
  - Start of validating the manufacturing concepts using analytical or laboratory experiments
  - Materials and/or processes have been characterized for manufacturability and availability, but further evaluation and demonstration is required
  - Experimental hardware models with limited functionality have been developed in a laboratory environment



# MRLs 4-5

- MRL 4: Capability to produce the **technology in a laboratory environment**
  - Technologies should have matured to at least TRL 4
  - Required investments (e.g. manufacturing technology development) have been identified
  - Processes to ensure manufacturability, producibility, and quality are sufficient to produce technology demonstrators
  - Manufacturing risks have been identified for building prototypes and mitigation plans are in place
  - Target cost objectives have been defined and manufacturing cost drivers have been identified
  - Producibility assessments of design concepts have been completed
  - Key design performance parameters, special tooling, facilities, material handling and skills required have been identified
- MRL 5: Capability to produce **prototype components in a production relevant environment**
  - Technologies should have matured to at least TRL 5
  - Potential manufacturing sources have been assessed
  - Manufacturing strategy integrated with the risk management plan has been made
  - Enabling/critical technologies and components have been identified
  - Prototype materials, tooling and test equipment, 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 started
  - Producibility assessments of key technologies and components are ongoing
  - A cost model regarding projects manufacturing cost has been constructed



# MRL 6

- MRL 6: Capability to produce **a prototype system or subsystem in a production relevant environment**
  - Technologies at TRL 6
  - A preliminary system design has been accepted
  - An initial manufacturing approach has been developed
  - The majority of manufacturing processes have been defined and characterized
  - Preliminary design has been completed, but the system has still significant engineering and/or design changes
  - Prototype manufacturing processes and technologies, materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment
  - Cost, yield and rate analyses have been performed to assess how prototype data compare to target objectives
  - Program for appropriate risk reduction to achieve cost requirements or establish a new baseline exists
  - Long-lead and key supply chain elements have been identified



# MRL 7

- MRL 7: Capability to produce **systems, subsystems, or components in a production representative environment**
  - Technologies should be on a path to achieve TRL 7
  - System detailed design activity is near completion
  - Material specifications have been approved and materials are available to meet the planned pilot line build schedule.
  - Manufacturing processes and procedures have been demonstrated in a production representative environment
  - Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway
  - The cost model has been updated with detailed designs, rolled up to system level, and tracked against allocated targets
  - Unit cost reduction efforts have been prioritized and are underway
  - Yield and rate analyses have been updated with production representative data
  - The supply chain and supplier quality assurance have been assessed and long-lead procurement plans are in place
  - Manufacturing plans and quality targets have been developed
  - Production tooling and test equipment design and development efforts are underway and validation plans for special test equipment or special inspection equipment are complete



# MRL 8

- MRL 8: Pilot line capability demonstrated; **ready to begin Low Rate Initial Production (LRIP)**
  - Technologies should have matured to at least TRL 7 or 8
  - Detailed system design is complete and sufficiently stable to enter low rate production
  - All materials, manpower, tooling, test equipment and facilities are proven on the pilot line and are available to meet the planned low rate production schedule
  - Test and inspection equipment have been validated as part of pilot line validation in accordance with validation plans
  - Manufacturing and quality processes and procedures have been proven on a pilot line and are under control and ready for low rate production
  - Known producibility risks pose no significant challenges for low rate production
  - Cost model and yield and rate analyses have been updated with pilot line results
  - Supplier qualification testing and first article inspection have been completed
  - The industrial capabilities assessment has been completed and shows the supply chain is established to support LRIP



# MRL 9

- MRL 9: Low rate production demonstrated; **capability in place to begin Full Rate Production (FRP)**
  - At this level, the system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production
  - Technologies should have matured to TRL 8 or 9. This TRL is normally associated with readiness for entry into FRP
  - All systems engineering/design requirements should have been met such that there are minimal system changes
  - Major system design features are stable and have been proven in test and evaluation
  - Materials, parts, manpower, tooling, test equipment and facilities are available to meet planned rate production schedules
  - Test and inspection equipment accepted and revalidated as necessary
  - Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances
  - Production risk monitoring is ongoing
  - LRIP cost targets have been met, and learning curves have been analyzed with actual data
  - The cost model has been developed for FRP and reflects the impact of continuous improvement



# MRL 10

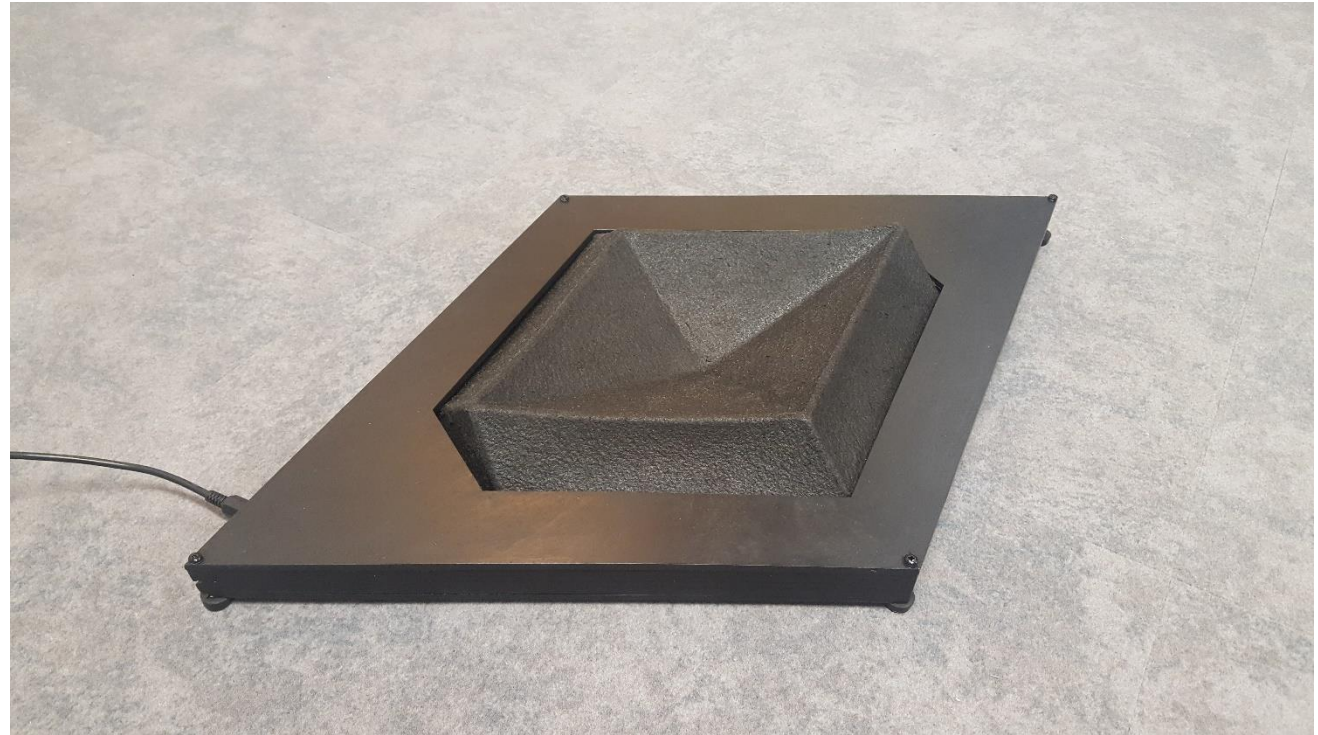
- MRL 10: **Full Rate Production demonstrated** and **lean production practices in place**
  - Technologies should have matured to TRL 9
  - Engineering/design changes are few and generally limited to quality and cost improvements
  - System, components, or items are in full rate production and meet all engineering, performance, quality and reliability requirements
  - Manufacturing process capability is at the appropriate quality level
  - All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements
  - Test and inspection equipment validation maintained and revalidated as necessary
  - 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





## Case study: Salmiakki

- Possibilities to combine esthetics and functionality
- Main technologies
  - Nanocellulose (NCF)
  - Carbon nanotubes (CNT)



(Siljander et al. 2018)

## Case study: NCF-CNT Automotive interior panel

- Similar to Salmiakki, possibilities to combine esthetics and functionality
- Main technologies
  - Nanocellulose (NCF)
  - Carbon nanotubes (CNT)
- NCF-CNT panels would not require Non-Woven Mat process stage



Figure: Traditional door panel

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
		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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Industrial base capabilities assessment 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 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 assessment for FRP has been completed and capability is in place to support start of FRP.	Industrial capability supports FRP and is assessed to support modifications, upgrades, surge and other potential manufacturing requirements.

# A - Technology and Industrial Base

## A.1 Industrial Base

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
	New manufacturing concepts and potential solutions identified.	Manufacturing technology concepts identified through experiments/models.	Manufacturing Science & Advanced Manufacturing Technology requirements identified.	Required manufacturing technology development efforts initiated, if applicable.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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.

# A - Technology and Industrial Base

## A.2 Manufacturing Technology Development



MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
		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 acquisition 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 & verify in production.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Producibility assessments and producibility trade studies (performance vs. producibility) of key technologies/components completed. Preliminary design choices assessed against manufacturing processes and industrial base capability constraints. Producibility enhancement efforts (e.g. Design For Manufacturing, Assembly, etc.) initiated.	Detailed producibility trade studies using knowledge of design characteristics and related manufacturing process capability completed. Producibility enhancement efforts 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 manufacturing sources & material shortages and other changes assessed for producibility.

## B - Design

### B.1 Producibility Program





MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
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.	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 potential key performance parameters 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 concepts.	Lower level performance requirements sufficient to proceed to preliminary design. All enabling/critical technologies and components identified and the product lifecycle considered. Evaluation of design Key Characteristics (KC) initiated. Product data required for prototype component manufacturing released.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 does not significantly impact LRIP. Key Characteristics are attainable based upon pilot line demonstrations.	Major product design features and configuration are stable. System design has been validated through operational testing of LRIP items. Physical configuration audit 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 in reaction to obsolescence. All KCs are controlled in FRP to appropriate quality levels.

## B - Design

### B.2 Design Maturity

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MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
	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 requirement 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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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.	FRP cost model updated with result of LRIP build.	Cost model validated against actual FRP cost.

## C - Cost & Funding

### C.1 Production Cost Knowledge (Cost modeling)

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MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
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 and alternative systems review.	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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 - Cost & Funding

### C.2 Cost Analysis





MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
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.	Manufacturing technology initiatives identified to reduce costs. Program has reasonable budget estimate for reaching MRL 6. 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. All outstanding MRL 5 risk areas understood with approved mitigation plans in place.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Program has reasonable budget estimate for reaching MRL 8. Estimate includes capital investment for production-representative equipment by CDR and pilot line equipment. All outstanding MRL 6 risk areas understood with approved mitigation plans in place.	Program has updated budget estimate for reaching MRL 8. 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.

## C - Cost & Funding

### C.3 Manufacturing Investment Budget



MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 engineering and manufacturing development 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 - Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)

### D.1 Maturity

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
	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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Availability issues addressed to meet engineering and manufacturing development build. Long-lead items identified. Components assessed for future diminishing manufacturing sources and material shortages (DMSMS) risk.	Availability issues addressed to meet LRIP builds. Long lead procurement 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.	Long lead procurement initiated for FRP. Availability issues pose no significant risk for FRP.	Program is in FRP with no significant material availability issues.

## D - Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)

### D.2 Availability

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MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
		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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Lifecycle supply chain requirements updated. Critical suppliers list updated. Supply chain plans in place (e.g. teaming agreements, etc.) supporting an engineering and manufacturing development 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 - Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)

### D.3 Supply Chain Management

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
	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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 LRIP. All work instructions contain special handling provisions as required.	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.

## D - Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)

### D.4 Special Handling (shelf life, security, hazardous materials, storage environment, etc.)

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MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
	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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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, assists in management of LRIP, and determines that FRP requirements can be met.	Models/simulation verified by FRP build. Production simulation models used as a tool to assist in management of FRP.

# E - Process Capability & Control

## E.1 Modeling & Simulation (Product & Process)

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MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
	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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 - Process Capability & Control

### E.2 Manufacturing Process Maturity

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
		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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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.

## E - Process Capability & Control

### E.3 Process Yields and Rates



MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
			Quality strategy identified as part of the acquisition strategy and included in systems engineering plan (SEP).	Quality strategy updated to reflect Key Characteristic identification activities.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 - Quality Management

## F.1 Quality Management

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
			Product inspection and acceptance testing strategy identified as part of the Acquisition Strategy and included in Engineering Plan (SEP).	Roles and responsibilities identified for acceptance test procedures, in-process and final inspections, and statistical process controls for prototype units.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 unrepeatable quality issues related to manufacturing processes. Results achieve targeted statistical level on all Key Characteristics. Results reflect continuous improvement.

# F - Quality Management

## F.2 Product Quality

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
			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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Supply base quality improvement initiatives identified addressing supplier Quality Management System shortfalls, including subtier supplier quality management.	Key supplier Quality Management 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.

## F - Quality Management

### F.3 Supplier Quality Management

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
		New manufacturing skills identified.	Manufacturing skill sets identified and production workforce requirements (technical and operational) evaluated as part of analysis of alternatives. Determine availability of process development workforce for the Technology Maturation and Risk Reduction Phase.	Skill sets identified and plans developed to meet prototype and production needs. Special skills certification and training requirements established.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Manufacturing 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.	Manufacturing 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.	Manufacturing 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.

# G - Manufacturing Workforce (Engineering & Production)

## G.1 Manufacturing Workforce

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
			Tooling/Special Test Equipment (STE)/Special Inspection Equipment (SIE) requirements are considered as part of analysis of alternatives.	Identify tooling and STE/SIE requirements and provide supporting rationale and schedule.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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 and validation plans for STE/SIE are complete. Manufacturing equipment maintenance strategy developed.	Tooling, test and inspection equipment proven on pilot line and additional requirements identified for LRIP. STE/SIE validated as part of pilot line validation IAW validation plan. Manufacturing equipment maintenance demonstrated on pilot line.	All tooling, test and inspection equipment proven in LRIP and additional requirements identified for FRP. Manufacturing equipment maintenance schedule demonstrated. STE/SIE validation maintained as necessary. Revalidation completed as necessary.	Proven tooling, test and inspection equipment in place to support maximum FRP. Planned equipment maintenance schedule achieved. STE/SIE validation maintained as necessary. Revalidation completed as necessary.

# H - Facilities

## H.1 Tooling / Special Test and Inspection Equipment

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Euroopan aluekehitysrahasto

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
		Specialized facility requirements/needs identified.	Availability of manufacturing facilities for prototype development and production evaluated as part of analysis of alternatives.	Manufacturing facilities identified and plans developed to produce prototypes.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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. Manufacturing facilities adequate to begin LRIP. Plans in place to support transition to FRP. Workplace safety is adequate.	Manufacturing 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.

# H - Facilities

## H.2 Facilities



MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
			Manufacturing strategy developed and integrated with acquisition strategy. Prototype schedule risk mitigation efforts incorporated into Acquisition Strategy.	Manufacturing strategy refined based upon preferred concept. Prototype schedule risk mitigation efforts initiated.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
Initial manufacturing approach developed. All system design related Manufacturing events included in Integrated Master Plan/Schedule (IMP/S). Manufacturing risk mitigation approach for pilot line or technology insertion programs defined.	Initial manufacturing plan developed. Manufacturing planning included in IMP/S. Manufacturing risks integrated into risk mitigation plans. Initial work instructions developed. Effective production control system in place to support pilot line.	Manufacturing plan updated for LRIP. All key manufacturing risks are identified and assessed with approved mitigation plans in place. Work instructions finalized. Effective production control system in place to support LRIP.	Manufacturing plan updated for FRP. All manufacturing risks tracked and mitigated. Effective production control system in place to support FRP.	All manufacturing risks mitigated.

# I - Manufacturing Management

## I.1 Manufacturing Planning & Scheduling

MRL 1	MRL 2	MRL 3	MRL 4	MRL 5
Basic manufacturing implications identified	Manufacturing Concepts Identified	Manufacturing Proof of Concept Developed	Capability to produce the technology in a laboratory environment	Capability to produce prototype components in a production relevant environment
			Technology development 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.
MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Capability to produce a prototype system or subsystem in a production relevant environment	Capability to produce systems, subsystems, or components in a production representative environment	Pilot line capability demonstrated; ready to begin Low Rate Initial Production (LRIP)	Low rate production demonstrated; Capability in place to begin Full Rate Production (FRP)	Full Rate Production demonstrated and lean production practices in place
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.

# I - Manufacturing Management

## I.2 Materials Planning



## MRLs – So what?

Not very interesting?

*”What is the MRL number of a case study XYZ?”*

More interesting?

*”What kind of technology and manufacturing information should exist to support full rate production regarding different manufacturing threads?”*



# *Thank you! Kiitos!*

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