

MANUFACTURING READINESS LEVEL DEFINITIONS

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

MRL 1: Basic Manufacturing Implications Identified

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

MRL 2: Manufacturing Concepts Identified

This level is characterized by describing the application of new manufacturing concepts. Applied research (i.e., funded by budget activity 6.2) translates basic research into solutions for broadly defined military needs. Typically, this level of readiness in the S&T environment includes identification, paper studies and analysis of material and process approaches. An understanding of manufacturing feasibility and risk is emerging.

MRL 3: Manufacturing Proof of Concept Developed

This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. This level of readiness is typical of technologies in the S&T funding categories of Applied Research and Advanced Development (i.e., funded by budget activity 6.3). Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.

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

This level of readiness is typical for S&T Programs in the budget activity 6.2 and 6.3 categories and acts as an exit criterion for the Materiel Solution Analysis (MSA) Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. At this point, required investments, such as manufacturing technology development, have been identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks have been identified for building prototypes and mitigation plans are in place. Target cost objectives have been established and manufacturing cost drivers have been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.

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

This level of maturity is typical of the mid-point in the Technology Development Phase of acquisition, or in the case of key technologies, near the mid-point of an Advanced Technology Demonstration (ATD) project. Technologies should have matured to at least TRL 5. The industrial base has been assessed to identify potential manufacturing sources. A manufacturing strategy has been refined and integrated with the risk management plan. Identification of enabling/critical technologies and components is complete.

Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts have been initiated or are ongoing. Producibility assessments of key technologies and components are ongoing. A cost model has been constructed to assess projected manufacturing cost.

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

This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the Engineering and Manufacturing Development (EMD) Phase of acquisition. Technologies should have matured to at least TRL 6. It is normally seen as the level of manufacturing readiness that denotes completion of S&T development and acceptance into a preliminary system design. An initial manufacturing approach has been developed. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. However, preliminary design of critical components has been completed and producibility assessments of key technologies are complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment. A cost analysis has been performed to assess projected manufacturing cost versus target cost objectives and the program has in place appropriate risk reduction to achieve cost requirements or establish a new baseline. This analysis should include design trades. Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been completed. Long-lead and key supply chain elements have been identified.

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

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

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

This level is associated with readiness for a Milestone C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is essentially complete and sufficiently stable to enter low rate production. All materials are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment and are under control and ready for low rate production. Known producibility risks pose no significant challenges for low rate production. The engineering cost model is driven by detailed design and has been validated with actual data. The Industrial Capabilities Assessment for Milestone C has been completed and shows that the supply chain is established and stable.

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

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 TRL9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement.

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

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

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

DEFINITION OF TERMS

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

Prior to Milestone B, MRLs focus on a contractor's capability to produce prototypes in a production relevant environment, outside of the laboratory. The parameters defining a production relevant environment should be based on the risks and uniqueness associated with demonstrating that contractors' key processes meet program requirements.

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

similar product (e.g. size, tolerances, quality levels, processes, and testing) in the facility intended to be used during production.

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

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

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

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

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

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

Two other definitions are germane to this discussion.

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

- Design for commonality and standardization—fewer parts
- Perform comprehensive technology assessment, including commercial industrial applications and the supplier base
- Design for multi-use and dual-use applications
- Design for modularity and plug compatible interface/integration
- Design for flexibility/adaptability or use “robust design”
- Utilize reliable processes and materials
- Utilize monolithic and determinant assembly
- Design for manufacturing and assembly
- Achieve production yield

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

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

Source for below: <https://acqnotes.com/acqnote/careerfields/manufacturing-readiness-levelmanufact>

Manufacturing Readiness Levels (TRL) Defined

Level	Definition	DoD MRL Description
1	Basic Manufacturing Implications Identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs.
3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.
4	Capability to produce the technology in a laboratory environment	This level of readiness acts as an exit criterion for the MSA Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.
5	Capability to produce prototype components in a production relevant environment	Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills, have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development.

Manufacturing Readiness Levels (TRL) Defined

Level	Definition	DoD MRL Description
6	Capability to produce a prototype system or subsystem in a production relevant environment	This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the EMD Phase of acquisition. Technologies should have matured to at least TRL 6. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself.
7	Capability to produce systems, subsystems, or components in a production representative environment	System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. Technologies should be on a path to achieving TRL 7.
8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production	The system, component, or item has been previously produced, is in production, or has successfully achieved low-rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP) . All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation.
9	Low rate production demonstrated; Capability in place to begin Full Rate Production	The system, component, or item has been previously produced, is in production, or has successfully achieved low-rate initial production (LRIP) . Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full-Rate Production (FRP) . All systems engineering/design requirements should have been met such that there are minimal system changes.
10	Full Rate Production demonstrated and lean production practices in place	Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. A system, components, or items are in full-rate production and meet all engineering, performance, quality, and reliability requirements. The manufacturing process capability is at the appropriate quality level.

Definition of Technology Readiness Levels

TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of- concept: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space): Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

TRL 7 System prototyping demonstration in an operational environment (ground or space): System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.

TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space): End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.

TRL 9 Actual system "mission proven" through successful mission operations (ground or space): Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Source: http://esto.nasa.gov/files/TRL_definitions.pdf

Source for below: <https://acqnotes.com/acqnote/tasks/technology-readiness-level>

Level	Definition	TRL Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include the integration of "ad hoc" hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment.	The Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment.
6	System/subsystem model or prototype demonstration in a relevant environment.	A representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness.
7	System prototype demonstration in an operational environment.	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space.
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluations of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system has proven through successful mission operations.	The actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.