APT
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Manufacturing Readiness Levels and Technology Readiness Levels in DoD Major Capability Acquisition

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Introduction

In this paper we begin with an examination of Science & Technology (S&T) and Manufacturing Technology (ManTech) projects as well as Pre-Acquisition Concepts, Experimenting, and Prototyping, all fundamental to product development. These activities "feed" the Department of Defense (DoD) Major Capability Acquisition (MCA) process from the Materiel Development Decision (MDD) through the Milestone C review. We include in this examination how assessments of technology and manufacturing maturity and risk integrate into this process.

Since the 1980s, GAO has consistently reported delays and cost overruns in DoD Major Defense Acquisition Programs (MDAPs). If a decision is made to develop and produce a design before the critical technology, design, or manufacturing knowledge is captured, problems will cascade and become magnified through the product development and production phases. Outcomes from these problems include increases in cost and schedule and degradations in performance and quality.[1]

GAO observed a correlation between programs that obtained certain knowledge at key points (especially risks in manufacturing and technology) and better cost and schedule outcomes. MDAPs that were knowledge-based acquisitions attained crucial information about topics such as technology maturity before proceeding beyond key points. But the majority of MDAPs GAO reviewed in the last 20 years continue to not obtain the knowledge that informs key investment decisions. This finding is consistently reported by GAO. Most recently, over half of the 26 MDAPs reported new delays as programs continue to make investment decisions without sufficient knowledge.[2]

If systems are truly designed using MOSA,[3] then they can be completed on time with proven subsystems, items, and components with the ability to upgrade to more advanced technologies and manufacturing processes as their maturity is achieved. This is the approach addressed in this paper.

OSD Policy and Guidance

Currently, DoDI 5000.85, *Major Capability Acquisition*, is concerned with acquisition policy once the acquisition decision is made at MDD. A graphical depiction of the "MCA model" in DoDI 5000.85 is as follows:

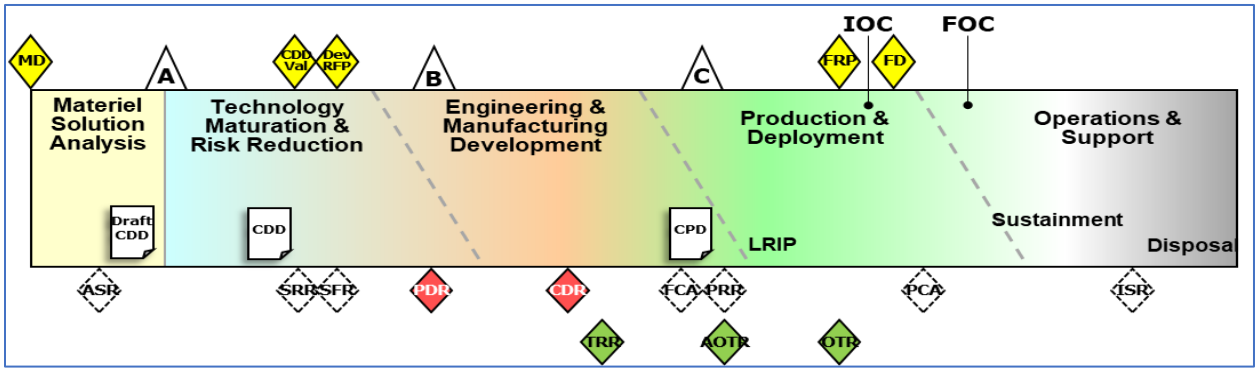

Figure 1 – MCA Model – Derived from DoDI 5000.85

[1] GAO-02-701, *Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*, Jul 2002

[2] GAO-23-106059, *Weapon Systems Annual Assessment*, Jun 2022

[3] Modular Open Systems Architecture is required by Title 10, USC

In DoDI 5000.88, *Engineering of Defense Systems*, the System Engineering (SE) and other processes are described without a graphic. This instruction adds earlier activities on pre-acquisition concepts, experiments, and prototypes prior to MDD such that the graphic left out of DoDI 5000.88 would be:

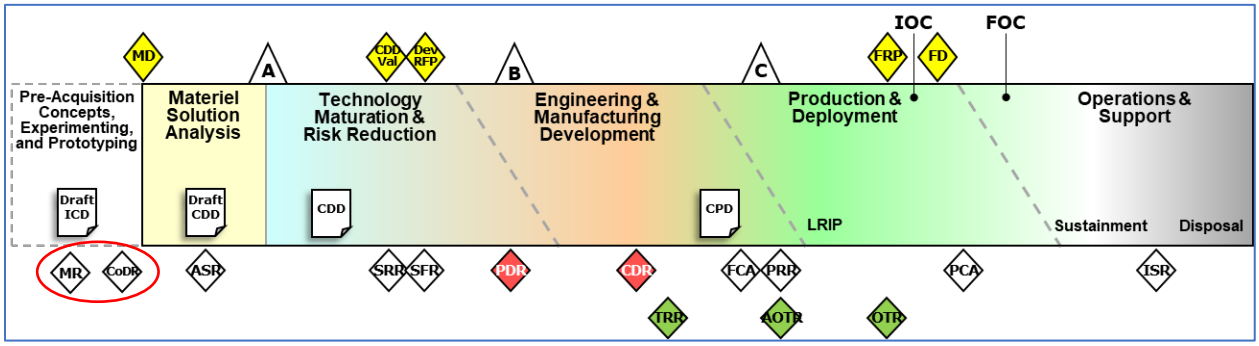

Figure 2 – MCA Life Cycle – Not Shown in DoDI 5000.88

Guidance for DoDI 5000.88 is found in the *Engineering of Defense Systems Guidebook,* Feb 2022, which adds to the description of pre-MDD activities by including the activities of enabling Science & Technology and Manufacturing Technology, which occur independently of the MCA process. This *Guidebook* describes the activities, processes, and practices involved in the development of DoD systems in Figure 3 below:

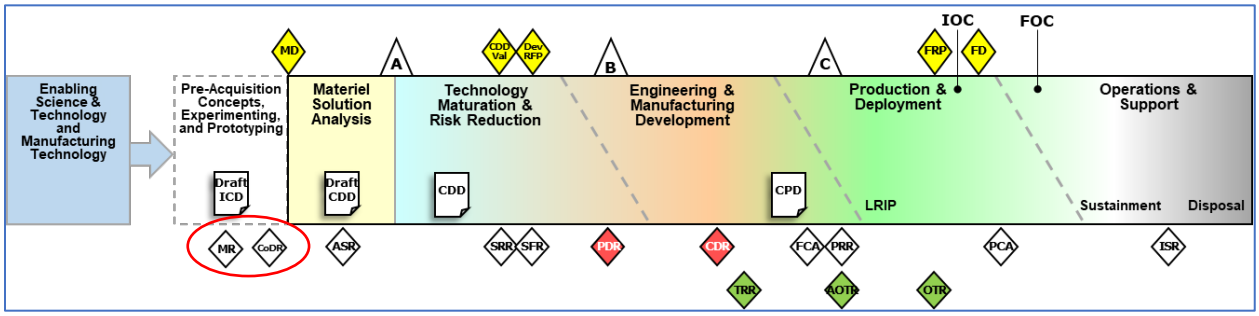

Figure 3 – MCA Life Cycle – Derived from Figure 3-1 in Guidebook

The *Guidebook* does not include the graphic depiction of the Mission Review (MR) diamond nor the Concepts Design Review (CoDR) diamond, shown in Figure 3, but does include discussion of MR and CoDR preceding the MDD. The authors added the diamonds for the two SE processes, MR and CoDR, to Figures 2 and 3 (highlighted by red ovals). The *Guidebook* also includes Pre-Acquisition Concepts, Experimenting, and Prototyping. We also separated the enabling S&T from the acquisition process and added ManTech to those activities to more accurately depict the process.

The discussion in the *Guidebook* ties Mission Engineering (ME) and the subsequent review back to the Joint Capabilities Integration Development System (JCIDS) requirements processes and selects appropriate concepts that could meet the need. The MR is primarily an OSD/R&E led effort focused on providing guidance for defining components and details of Mission Baselines and associated mission definitions.

Also discussed is the process of selecting preferred concepts in the CoDR. The CoDR is the culmination of concept exploration and DOTMLPF-P[4] evaluations to address preliminary solution trades to meet mission needs. The CoDR should be a multidisciplined review of the potential joint warfare concepts, Service-specific concepts, considerations to establish the Concept Baseline, and as such should include manufacturing and quality engineering analyses and inputs.[5]

Figure 3 is derived from "Figure 3-1 Major Capability Acquisition Life Cycle" in the *Guidebook* and depicts the end-to-end perspective and the integration of SE technical reviews and audits of the actual activities in the acquisition process and supporting the process. We will now discuss how Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs) integrate into these processes.

Enabling Science & Technology and Manufacturing Technology

Between Government and Industry S&T, R&D, and ManTech projects the technology maturity can range from TRL 1 to 7 and the manufacturing maturity from MRL 1 to MRL 7. These programs/projects develop technologies and products of varying maturities that can be integrated into either pre-MDD activities or ongoing acquisition programs.

As a separate effort from MCA, the range of maturity in S&T can be from very immature (TRL 1 or 2) to a mature demonstration in an operational environment (TRL 7). Maturing technology is not always responsive to funding and effort, and may not be achieved on a schedule. Technologies must be sufficiently mature, with technical risks judged to be acceptable, to warrant insertion in a program, which assumes that a sufficient level of manufacturing maturity is also met.

S&T programs:

- Use TRLs to measure progress in maturing technologies
- Should develop and mature technologies to a minimum of TRL 5
- May also develop unique manufacturing processes, procedures, or techniques

Figure 4

Also separate from MCA, DoD ManTech programs will develop manufacturing processes, procedures, and techniques for existing products, demonstrate application to new products, and develop manufacturing capabilities to the point where they can be integrated into production of the product. The ManTech programs are most often maturing manufacturing from MRL 4 to MRL 7.

Pre-acquisition Concepts, Experimenting and Prototyping

During pre-acquisition, early-stage ideas and strategies are examined before formal acquisition processes begin and concepts are explored for potential solutions envisioning novel approaches, while identifying capability gaps. Advanced technology demonstration programs play a crucial role in evaluating and maturing advanced technologies for potential use. Experimentation is performed using systematic testing and exploration to gain insights and validate approaches and hypotheses. Prototypes

[4] DOTMLPF-P – Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, Facilities, and Policy analysis
[5] *Engineering of Defense System Guidebook*, Feb 2022

are developed to validate designs, reduce technical risk, and gather feedback. Collectively, these are used to contribute to informed decision making, technological advancement, and development of capabilities. All of the above activities provide the basis or inputs to the engineering process described in both the *Engineering of Defense Systems Guidebook* and DoDI 5000.88, which results in identification of candidate concepts and alternatives that could meet the mission objective.

The Joint Staff conducts a Capabilities Based Analysis, and/or other studies as part of the JCIDS process, producing a draft Initial Capabilities Document (ICD). The draft ICD contains the initial Key Performance Parameters (KPP), Key System Attributes, and Additional Performance Attributes. The draft ICD is assigned to a lead Service or Services. Before determining if a materiel solution should be developed, the lead Service initiates activities to develop the Analysis of Alternatives (AoA) Study Plan, and the Director of Cost Assessment and Program Evaluation (DCAPE) will develop the AoA Study Guidance. Mission Engineering will conduct deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects. The MR is the culmination of requirements and mission engineering activities.

The CoDR is a multidisciplined review of the potential joint warfare concepts, Service-specific concepts, and considerations to establish the Concept Baseline. The CoDR should review the results of experimenting and prototyping these concepts including a review of manufacturing and quality engineering analyses and inputs. These activities should also include manufacturing feasibility assessment (Manufacturing Readiness Assessment using MRL process), studies from the S&T community, and other supporting studies (threat analysis, gap studies, etc.) contributing pertinent data and information for the MDD.

The prototypes, which have been developed to validate designs and reduce risk, should have been used to validate technologies in an environment that used the most stressing aspects of the operational environment. Systems for development should therefore not enter the Materiel Solutions Analysis (MSA) phase without having validation in a relevant environment.

As a result of the above activities, immature technologies will have been matured to between TRL 5 and 7 with a minimum of TRL 5 at the product level, which is the recommended entrance criterion for MDD. Manufacturing maturity could have likewise matured up to MRL 7, but should meet a minimum of MRL 3 as a recommended entrance criterion for MDD. (Figure 5)

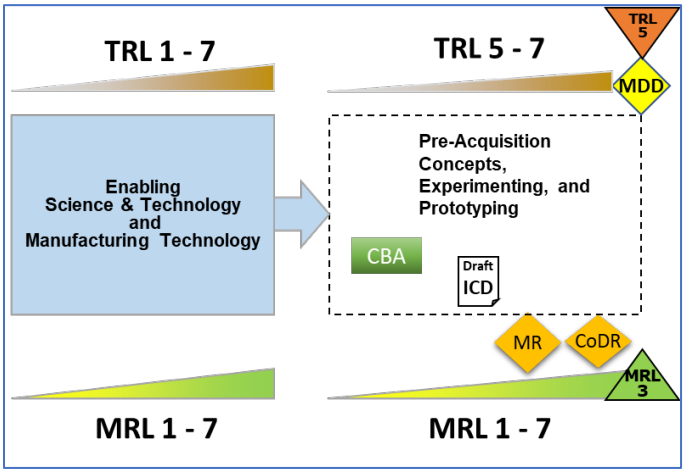

Figure 5

Recall that enabling S&T, ManTech development, and experimenting and prototyping with pre-acquisition concepts are continuously ongoing activities. They are separately funded and independent of any MCA or acquisition approach. Given that systems are designed with MOSA, the results of these activities can be inserted into acquisition programs at any point, commensurate with the maturity of the products and the program.

MDD to Milestone A

For MCA programs, the MSA phase precedes the Milestone A decision with requirements from DoDI 5000.85. According to DoDI 5000.85, the purpose of the MSA phase is to conduct the AoA and other activities needed to choose the concept for the product to be acquired, to begin translating validated capability gaps into system-specific requirements, and to conduct planning to support a decision on the Acquisition Strategy (AS) for the product. Other than requiring an Independent Cost Estimate (ICE), an Independent Technical Risk Assessment (ITRA), and beginning product support and sustainment planning; other activities are not specifically identified in DoDI5000.85.

The MSA phase is focused on identification of a preferred concept and analysis of alternatives, as guided by the ICD, the *AoA Study Guidance*, and *AoA Study Plan*.[6] Once a preferred materiel solution is selected, a Manufacturing Readiness Assessment (MRA) using the MRL process should be performed. At this point, both an ICE and an ITRA should be initiated with the performed MRA a required input to the ITRA. Both an ICE and an ITRA are required before granting Milestone A approval.[7] [8] [9]

According to DoDI 5000.88 unless waived, Systems Engineering Plans (SEPs) are required for all MDAPs and all ACAT II and III programs. During the MSA phase, the MRA assessment using the MRL process will be documented in the SEP.[10] An approved SEP is required for the Milestone A review. An Alternative Systems Review (ASR) is conducted by the Program Manager to assure the preferred materiel solution(s) meets requirements prior to the Milestone A review.[11] [12] Once the Program Manager has completed an ASR, the program can proceed to the Milestone A decision point.

At a Milestone A review, approval of program entry into the Technology Maturation and Risk Reduction (TMRR) phase occurs. The Milestone Decision Authority (MDA) will approve the program AS, any Program Manager waivers requested, release of the final RFPs for TMRR activities, exit criteria for TMRR, and entrance criteria for Engineering and Manufacturing Development (EMD) phase.[13] To ensure that adequate knowledge of technology and manufacturing risks is available to support all of the decisions required at Milestone A, the least mature technology at the product level should preferably be TRL 6, with manufacturing maturity achieving a minimum MRL 4.

[6] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020, §3.6.a
[7] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020, §3.6.b(3)
[8] *Independent Cost Estimate* and §2334 & §2366a of Title 10 USC
[9] *Independent Technical Risk Assessment* and §2448 of Title 10 USC
[10] DoDI 5000.88, *Engineering of Defense Systems,* Nov 2020
[11] *Engineering Defense Systems Guidebook*, §3.2.1.3.1 and Table 3.14
[12] *Systems Engineering Guidebook*, §3.1
[13] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020

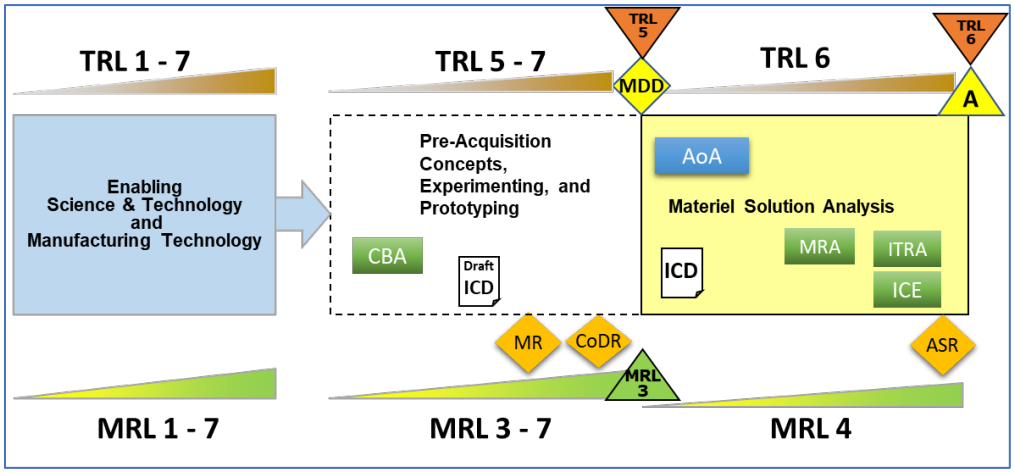

Figure 6

TMRR

The purpose of this phase is to reduce technology, engineering, integration, and life-cycle cost risk to the point that a decision to contract for EMD can be made with confidence in successful program execution for development, production, and sustainment.[14] The focus for TMRR should be on maturing subsystems, items, and components to ensure product preliminary design is sufficiently robust to proceed into system/product engineering and manufacturing development with minimal risks.

During the TMRR phase the following activities and objectives are included:[15]

- Determining the appropriate [mature] technologies to integrate [into] the full system
- Maturing and demonstrating technologies in a relevant environment[16]
- Conducting prototyping of the system and/or system elements[17]
- Performing trade studies and using the results to refine requirements and revise the design concept(s)
- Developing the preliminary design including establishing the functional and allocated baselines and associated specifications
- Performing development test activities as appropriate

During this phase, the acquisition strategy and product support & sustainment planning continue to develop. Program security and program protection requirements will be evaluated. An MRA using the MRL process will be performed as required by the SEP and is a critical input to the required ITRAs.[18] An ICE and an ITRA will be conducted for MDAPs (before granting Milestone B approval), as will a Preliminary Design Review (PDR). Also, this phase normally includes multiple competitive sources

[14] Ibid
[15] *Early Manufacturing and Quality Engineering Guide*, Jul 2022
[16] Relevant environment – Testing environment that simulates both the most important and most stressing aspects of the operational environment. *TRA Guide,* Jun 2023
[17] A system prototype is necessary for TRL 7 demonstration in and operational environment. *TRA Guide,* Jun 2023
[18] See conclusions in *Essential Elements of SE in Early DoD MCA*, Apr 2023

conducting technology risk reduction activity to demonstrate new technologies in a relevant environment. Development testing will be guided by the test and evaluation master plan.[19]

DoD has determined that prior to the end of the TMRR phase, a review to establish that an executable and affordable program is planned with a sound business and technical approach. This review is called the Development RFP Decision Point. At this decision point the programmatic requirements are considered and incorporated into the EMD RFPs. Decisions included are initial production quantity, source selection criteria, contract incentives, the intellectual property strategy, threat projections, assessments of Foreign Ownership, Control or Influence (FOCI), and the use of MOSA to evolve systems capability, and establish and maintain interoperability. The MDA will approve the release of the final RFP for the EMD Phase.

Requirements for the Milestone B review may have been satisfied at the Development RFP Release decision point; however, if significant changes have occurred between the two decisions that would alter the decisions made at the earlier point, those changes will be addressed at the Milestone B review.

The Milestone B review requires:

- Demonstration that all sources of risk have been adequately mitigated (supporting a commitment to design, development, and production)
- Validated capability requirements (for all programs)
- Full funding in the FYDP
- Compliance with affordability/program goals (demonstrated through technical assessments – MRLs and ITRAs)
- ICEs for MDAPs and programs in other categories when directed[20]
- PDR complete[21]

The Milestone B decision authorizes a program to enter into the EMD phase and commit[s] the required investment resources to support the award of phase contracts. Risk sources for mitigation include, but are not limited to technology, manufacturing, threat projections, security, engineering, integration, sustainment, and cost.

Based on decades of reporting on DoD MDAPs, GAO has found that if a project [system/product] has a lower than recommended TRL, less than TRL 7 by PDR[22], then the project does not have a solid technical basis for its design and the program could put itself at risk of approving a design that is less likely to remain stable.[23] Therefore, at Milestone B and the entrance to the EMD Phase, the least mature technology at the product level should be developed and preferably meet TRL 7, with manufacturing maturity achieving a minimum MRL 6.

[19] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020
[20] Ibid
[21] DoDI 5000.88, *Engineering of Defense Systems,* Nov 2020

[22] Recall that meeting TRL 7 is testing of a system prototype of an actual operational system in an operational environment, i.e., one that addresses user operational requirements and specifications to include platform and/or packaging.
[23] GAO-20-48G *Technology Readiness Assessment Guide*, Jan 2020

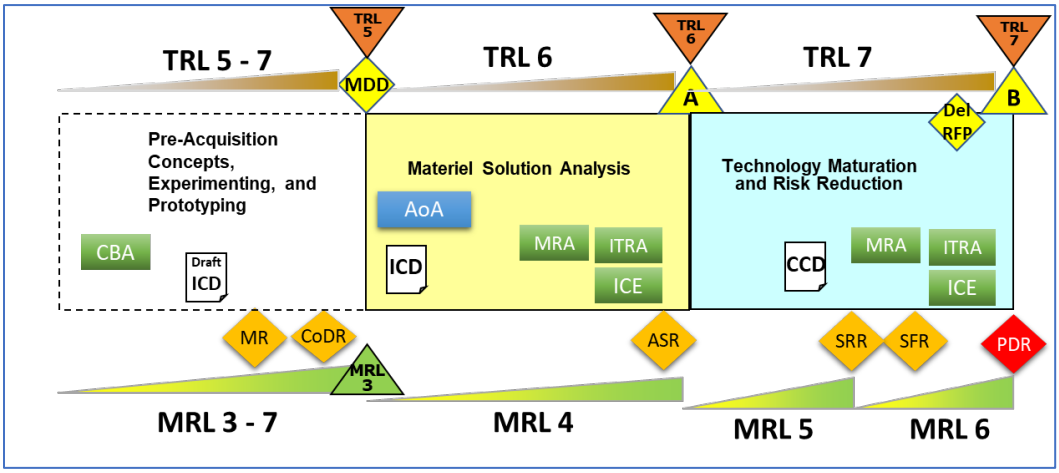

Figure 7

EMD Phase

At a successful Milestone B review, the MDA will approve entry into the EMD phase and approve the Acquisition Program Baseline. These program decisions, along with EMD phase exit criteria, approval of the initial production quantity, and specific technical event-based criteria for initiating production or fielding at Milestone C will be documented in an Acquisition Decision Memorandum.[24]

"The purpose of the EMD phase is to develop, build, test, and evaluate a materiel solution [preproduction development products] to verify that all operational and implied requirements, including those for security, have been met, and to support production, deployment and sustainment decisions."[25]

Product Development

Early in EMD, from Milestone B to Critical Design Review (CDR), product development will complete all needed hardware and software detailed designs to include: [26]

- Completion of product baseline and detailed design for production
- Verification that product performance requirements met
- Completion of designs for all internal and external interfaces
- Completion of identification and development of key manufacturing processes and key characteristics in a production-representative environment
- Documentation of bi-directional traceability between functional and allocated baselines and detailed designs
- Completion of design analyses to develop critical part and long lead production requirements

The CDR shall be conducted, with input from an MRA, to help ensure that the detailed design for the system under review is adequate to proceed into fabrication, system integration, demonstration and test, and can meet stated performance requirements within budget, schedule, risk, and other system constraints. A CDR assesses design maturity, design build-to or code-to documentation, and remaining

[24] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020
[25] Ibid
[26] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020

risks, and establishes the initial technical baseline. At this point, the minimum TRL is 7 with a minimum MRL of 7.

Product Demonstration

Post CDR, EMD product demonstration will include:[27]

- Developmental testing and evaluation will be conducted demonstrating ability to achieve KPPs
- Finalized designs for Product Support elements and integration into a comprehensive, documented in a strategy document (i.e., PSS)
- Training devices will be funded, designed, and developed

The EMD phase will end when:[28]

- Design is stable
- System meets validated capability requirements (demonstrated by developmental, live fire, and early operational testing
- Manufacturing processes have been effectively demonstrated and are under control
- Software sustainment processes are in place and functioning
- Industrial production capabilities are reasonably available
- Program security remains uncompromised
- All directed EMD phase exit criteria and Milestone C entrance criteria per the MDA's have been met or exceeded
- An MRA and a Production Readiness Review (PRR) have been conducted (in support of the ICE and ITRA)
- An ICE and an ITRA have been conducted

Milestone C

Milestone C is the point at which a program is reviewed for entrance into the Production & Deployment (P&D) phase. At the Milestone C review, the following information will typically be considered:[29]

- Results of developmental tests and evaluations
- Early operational test and evaluation
- Evidence that the production design is stable
- Results of an operational assessment
- Maturity of the software
- Any significant manufacturing risks
- Status of critical intelligence parameters
- Intelligence mission data requirements, relative to fielding timelines
- Full funding

[27] Ibid
[28] Ibid
[29] DoDI 5000.85, *Major Capability Acquisition,* Aug 2020

What is not explicitly stated in DoDI 5000.85, the Milestone C review includes consideration of the results of the MRA, the PRR, the ICE, and the ITRA. These are included in the review of production design stability, software maturity, manufacturing risks, funding, and fielding requirements.

The MDA's decision to approve Milestone C will authorize the program to proceed to the P&D phase, enter initial production, and award contracts for the phase. At this point, the minimum is TRL 8 with a minimum of MRL 8.

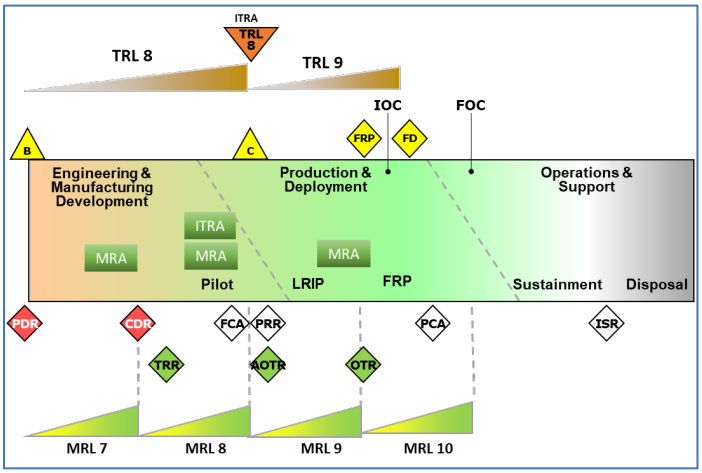

Figure 8

Summary

In this paper, we examined enabling S&T, ManTech, as well as Pre-Acquisition Concepts, Experimenting, and Prototyping, all fundamental to product development. We demonstrated how these activities feed the MCA process from MDD through the Milestone C review. We also demonstrated how the assessments of technology and manufacturing risks integrate into this process.

For a more in-depth discussion of the essential elements of SE, or the essential manufacturing activities in early DoD MCA, refer to our papers found on the APT-US.com website:

- *Essential Elements of Systems Engineering in Early DoD MCA*, Apr 2023
- *Essential Manufacturing & Quality Activities in Early DoD MCA*, Apr 2023

Based on the discussion in this paper, Figure 3 (repeated below) is a more accurate depiction of the pre-acquisition activities and the *Major Capability Acquisition Process* shown in DoDI 5000.85. The figure is also a more accurate depiction of the processes described in the *Engineering of Defense Systems Guidebook* and in DoDI 5000.88; it should be included in those documents. Figure 3 should be uniformly shown in all policy and guidance documents on DoD MCA.

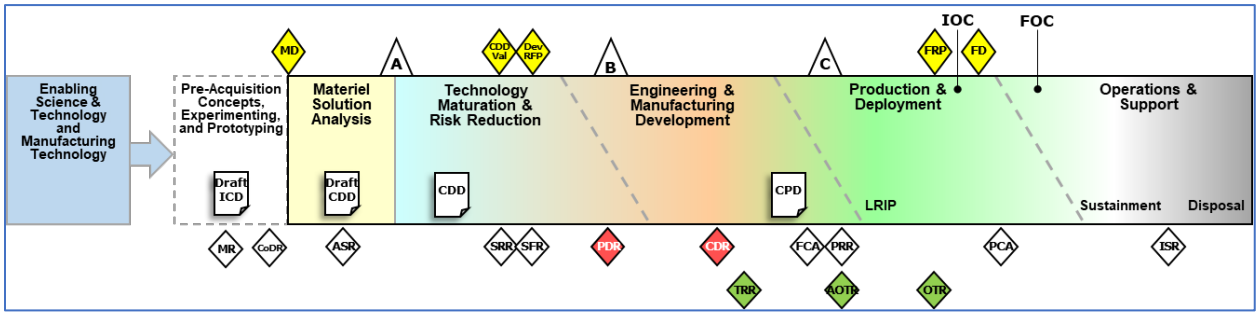

Figure 3 – MCA Life Cycle

Many of the technologies and manufacturing processes are developed and matured during the early phases before the acquisition process begins. During S&T and ManTech development projects, maturity can be advanced to almost "operational" levels (TRL 7 and MRL 7). The planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects are part of the ME process prior to MDD including experimenting and prototyping. All of these activities should enable candidate concepts to mature to a minimum of TRL 5 and MRL 3 for the MDD.

The MSA phase is focused on identification of a preferred concept and analysis of alternatives, as guided by the ICD, the *AoA Study Guidance*, and *AoA Study Plan*. Once a preferred materiel solution is selected, an MRA, an ICE, and an ITRA are be performed. The selected solution is the one that provides adequate knowledge of technology and manufacturing risks with the least mature technology at the product level of TRL 6 and manufacturing maturity achieving a minimum MRL 4 for a Milestone A decision.

The TMRR phase purpose is to reduce technology, engineering, integration, and life-cycle cost risk to the point that a decision to contract for EMD can be made with confidence in successful program execution for development, production, and sustainment. The focus for TMRR should be on whether subsystems, items, and components are sufficiently matured to ensure product preliminary design is robust and ready to proceed into system/product engineering and manufacturing development with minimal risks.

If a system or product has less than TRL 7 by PDR, the program does not have a solid technical basis for its design and could be at risk of approving a design that is less likely to remain stable. At Milestone B, the least mature technology at the product level should preferably meet TRL 7 and manufacturing maturity achieving a minimum MRL 6.

The purpose of the EMD phase is to develop, build, test, and evaluate a materiel solution and verify that all operational and implied requirements, including those for security, have been met, and to support production, deployment, and sustainment decisions. In the early EMD, from Milestone B to CDR, product development will complete all needed hardware and software detailed designs. At the CDR, the minimum TRL is 7 with a minimum MRL of 7. Post-CDR, the program proceeds into fabrication, system integration, and demonstration and test; meeting stated performance requirements within budget, schedule, risk, and other system constraints. The EMD phase ends with the MDA's decision at Milestone C to approve and authorize the program to proceed to the P&D phase and enter initial production. At this point, the least mature technology at the product level should meet TRL 8 and manufacturing maturity achieving a minimum MRL 8.

In addition, Figure 9 (below) shows the end-to-end perspective, the alignment of technology and manufacturing maturity, and the integration of SE technical reviews and audits for all pre-acquisition

and MCA Life Cycle activities more accurately than Figure 2-3, the current graphic in the *MRL Deskbook 2022*. Figure 9 should replace the current graphic.

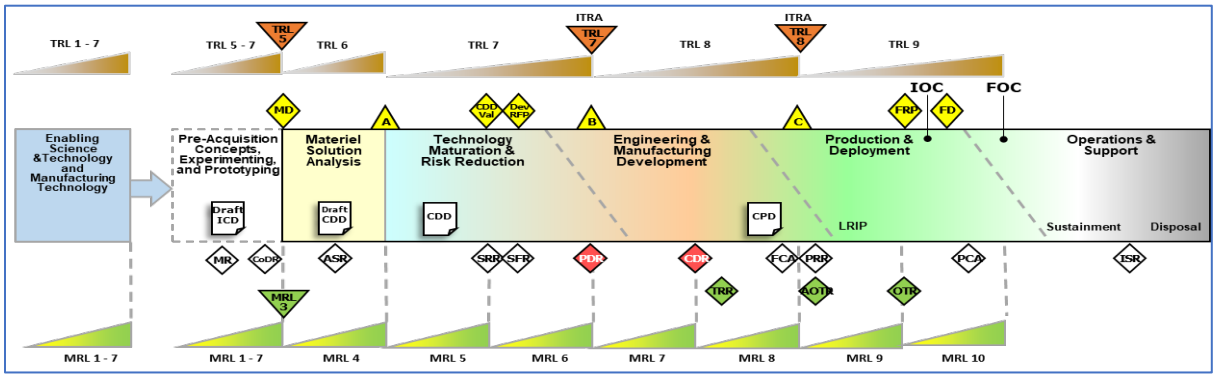

Figure 9 – MCA Life Cycle with MRL and TRL Alignment

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1. *Essential Elements of Systems Engineering in Early DoD MCA*, Apr 2023
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