Managing Manufacturing Maturity and Risks by Applying Department of Defense Manufacturing Readiness Assessment and Manufacturing Readiness Levels Process to a Military Weapons System

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Abstract — *In the 1990's the Department of Defense, as part of the Acquisition Process Reform, started reducing and eliminating Manufacturing and Quality Assurance instructions, guidance, Mil-Specs and Standards, relying on the private sector to establish and manage these requirements. This in turn caused the loss of government Acquisition Manufacturing personnel and loss of the knowledge needed to identify and manage manufacturing maturity and risks associated with military weapon systems. In recent years the Department of Defense has recognized and is pushing to improve this deficiency. The following project discussion presents the application of Manufacturing Readiness Assessment process and Manufacturing Readiness Level to an US Air Force line replaceable unit device for a military aircraft. The end result is to provide the information necessary to the Support Program Office that manages the project contract, to determine manufacturing readiness and manage manufacturing risks through a Manufacturing Maturation Plan.*

Key Terms — *Department of Defense Acquisition Process, Manufacturing Maturation Plan, Manufacturing Readiness Assessment, Manufacturing Readiness Levels.*

PROBLEM STATEMENT

A United States Air Force (USAF) Support Program Office (SPO) is managing a contract with prime contractor ABC to develop and implement a new electrical power Line Replaceable Unit (LRU) device for a military aircraft. According to the program master schedule, the program reached the time to start initial regular production, known as Low Rate Initial Production (LRIP), of the new LRU device. Before proceeding with the start of production, a manufacturing readiness review is required as established in the contract. This project demonstrates the application of Manufacturing Readiness Assessment (MRA) process and Manufacturing Readiness Level (MRL), as defined in the DoD MRL Deskbook [1], in performing the assessment to determine manufacturing process readiness and associated risks if and when regular production is started.

RESEARCH DESCRIPTION

This project will describe the methodology and tools necessary to perform a manufacturing readiness assessment for a USAF program. The MRA tool will be used to perform the assessment.

RESEARCH OBJECTIVES

The main objective of this project is to conduct a manufacturing readiness assessment to determine if the contractor manufacturing operation is at the correct maturity level required to officially initiate regular device production, or LRIP.

RESEARCH CONTRIBUTIONS

Based on the acquisition process, described later on in the Literature Review section, entering LRIP is a milestone C (MS-C) step with specific entry and exit criteria. The manufacturing assessment provided the SPO's Program Manager (PM) and Chief Engineering (CE) the necessary information to determine if the manufacturing readiness criteria were met, consequently approving or disapproving

the initial product ramp up. A Manufacturing Maturation Plan (MMP) [1] was also developed to address the corrective actions to bring the assessed manufacturing process to appropriate maturity level.

LITERATURE REVIEW

The Department of Defense (DoD) Acquisition Process [2] [3] for military weapon systems provides the steps to follow from concept of the capabilities desired for the weapon system through operations/support and finally end of life of the system. Three main drivers for any acquisition program are cost, schedule and performance (which include the quality element).

The acquisition process is organized in five phases, with three System Acquisition milestones at different stages of the process.

The phases include:

- Capabilities Based Planning /Concept Development (CBP/CD)
- Materiel Solution Analysis (MSA)
- Technology Maturation & Risk Reduction (TMRR)
- Engineering & Manufacturing Development (EMD)
- Production & Deployment /Operations & Support. (P&D/O&S)

The milestones (MS) include:

- MS-A prior to entering TMRR
- MS-B prior to entering EMD
- MS-C prior to entering P&D/O&S

Each milestone has a series of entry and exit criteria to be met before the program can proceed to the next phase. Every acquisition program must follow these processes or a tailored version for specific program needs. Figure 1 illustrates acquisition phases and milestones.

Figure 1
DoD Acquisition Phases and Milestones

The MRA is a method to evaluate technology, component, manufacturing process, weapon systems or subsystems. It is expected to start along with the first acquisition process phase CBP/CD, and all the way through O&S phase. In other words, it is applicable throughout and each step of the acquisition process described. This assessment results in identification of the manufacturing maturity level, associated potential risks, and risk management strategy.

The MRA process utilizes MRL to perform the assessment. There are ten MRL levels (1 through 10) as shown in Table 1.

Table 1
MRL Levels Definitions

MRL LEVEL	DEFINITION
MRL-1	Basic manufacturing implications identified (5 criteria/questions)
MRL-2	Manufacturing concepts identified (12 criteria/questions)
MRL-3	Manufacturing Proof of Concepts developed (24 criteria/questions)
MRL-4	Capability to produce the technology in a laboratory environment (43 criteria/questions)
MRL-5	Capability to produce prototype components in a production relevant environment (50 criteria/questions)
MRL-6	Capability to produce a prototype system or subsystem in a production relevant environment (61 criteria/questions)
MRL-7	Capability to produce systems, subsystems, or components in a production representative environment (61 criteria/questions)
MRL-8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production (LRIP) (69 criteria/questions)
MRL-9	Low Rate Production demonstrated; Capability in place to begin Full Rate Production (FRP) (54 criteria/questions)
MRL-10	Full Rate Production demonstrated and lean production practices in place (39 criteria/questions)

Figure 2 shows the interaction between the acquisition process phases and the applicable MRL per phase.

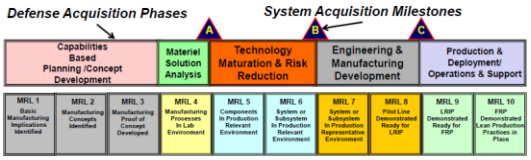

Figure 2
Applicable MRL per DoD Acquisition Phases/Milestones

Each MRL address nine threads (A through I) and each thread address several sub-threads as shown in Table 2. Per the MRL Users Guide [4], the combination of all threads/sub-threads produces 418 criteria/questions that are used to perform the assessments at different stages of the acquisition process. Table 1 also showed the criteria/questions distribution per MRL.

Table 2
MRL Threads and Sub-Threads

THREAD	SUB-THREAD
A-Technology & Industrial Base	A.1- Technology Transition to Production A.2 - Manufacturing Technology Development
B-Design	B.1 - Producibility Program B.2 - Design Maturity
C-Cost & Funding	C.1 - Production Cost Knowledge (Cost modeling) C.2 - Cost Analysis C.3 - Manufacturing Investment Budget
D-Materials (Raw Materials, Components, Sub-assemblies and Sub-systems)	D.1 – Maturity D.2 – Availability D.3 - Supply Chain Management D.4 - Special Handling
E-Process Capability & Control	E.1 - Modeling & Simulation E.2 - Manufacturing Process Maturity E.3 - Process Yields and Rates
F-Quality Management	F.1 - Quality Management including Supplier Quality F.2 - Product Quality F.3 - Supplier Quality Management
G-Mfg. Workforce (Engineering & Production)	G.1 - Manufacturing Personnel
H-Facilities	H.1 - Tooling/ Special Test and Inspection Equipment (STE/SIE) H.2 - Facilities
I-Mfg. Management	I.1 – Mfg. Planning & Scheduling I.2 - Materials Planning

Finally, when an assessment is performed at any phase and the MRL requirement is not met for that phase because it is lower than required, the Program Manager has three alternatives to choose from:

- Approve a program schedule delay to allow completion of a corrective action plan. This alternative could negatively impact schedule and cost, although would reduce manufacturing risks.
- Select a different design which could be more suitable for manufacturing. This alternative could negatively impact schedule, cost and performance, and does not ensure manufacturing risks would be reduced with the new design.
- Decide to carry a risk and proceed to enter MS-C and LRIP. A MMP must accompany this decision. Schedule is not delayed in this case.

The MMP is developed to ensure that the appropriate level of manufacturing maturity will be reached at the next decision making point. It is delivered along with the results of the assessment of manufacturing readiness. Table 3 shows the main elements that make up the MMP.

Table 3
MMP Outline

MMP Outline	
1-	Title
2-	Statement of the problem
3-	Solution options
4-	Maturation plan with schedule and funding breakout
5-	Key activities for the preferred approach
6-	Preparations for using an alternative approach
7-	The latest time that an alternative approach can be chosen
8-	Status of funding to execute the manufacturing plan
9-	Specific actions to be taken (what will be done and by whom)
10-	Prototypes or test articles to be built
11-	Test to be run
12-	Threshold performance to be met
13-	MRL to achieve and when it will be achieved

The risk addressed in the MMP are based in the understanding of the reasons the MRL did not meet the target and understanding of the impact they would have in the program in cost, schedule and performance throughout its life. Risks are also

linked to airworthiness, which in simple terms means the aircraft is safe to take off, sustain flight, and land without placing under risk the crew, aircraft, property and people on the ground. Airworthiness is defined by MIL-HDBK-516B [5] which is transitioning to version C in 2015. Figure 3 shows the risk acceptance matrix [6] used to calculate risk based on severity and frequency of the hazard could occur (a risk by definition is an event that has not occurred yet). Risks are defined as low, medium, serious or high.

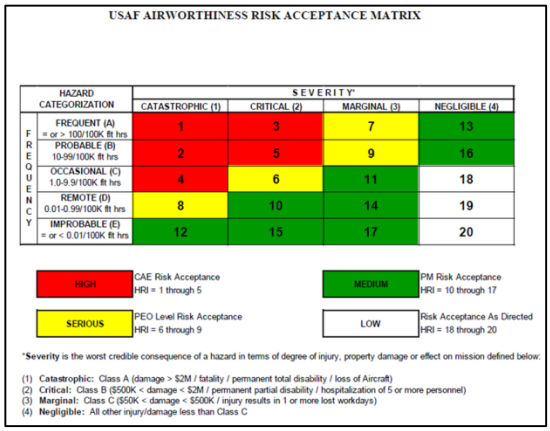

Figure 3
USAF Airworthiness Risk Acceptance Matrix

PROJECT METHODOLOGY

The methodology to perform a MRA review was based on MRL Deskbook [1]. For this research project the program entrance to MS-C and start of the LRIP production required an MRL of 8. At this level the manufacturing process maturity is being demonstrated on a pilot line. All materials are ready for LRIP. Manufacturing processes are now proven and the supply chain is stable for LRIP.

1. Determine Initial Assessment Scope: The SPO Program Manager (PM) along the Systems Integration Engineer (SIE) established the initial scope and schedule with the prime contractor, which in turn coordinated with their subcontractor. This assessment was in preparation to the initial production build which requires meeting milestone C entry/exit requirements. The required MRL at this stage is level 8.
2. Determine Assessment Taxonomy and Schedule: The taxonomy, which refers to deciding what to assess, location of the assessment, and who will conduct the assessment. For this program the manufacturing process for the electric power LRU was assessed, at the sub-contractor manufacturing facility and lead by the prime contractor jointly with the USAF.
3. Form and Orient Assessment Team: Two teams were organized. One from the prime contractor and one from the USAF. Members for the USAF team were selected based on systems, quality, electrical and manufacturing engineering and supply chain/procurement knowledge. A brief training in MRA/MRL concepts was provided to familiarize/refresh team members. Team names were provided to the prime contractor for proper clearance.
4. Orient Contractors Being Assessed: In this assessment, the prime contractor provided the orientation to the subcontractor. USAF inputs were included. The prime contractor was informed that MRL questionnaire for level 8 would be used for the assessment. Sixty-nine (69) criteria/questions encompassing all nine threads discussed in the Literature Review section address level 8. Table 4 shows a sample of the 69 questions. It includes samples of all treads and sub-threads.
5. Request Contractors to Perform Self-Assessment: The prime contractor requested the subcontractor to conduct a self-assessment of where they believe their manufacturing readiness was to start with the initial production of the LRU. An assessment was provided by the subcontractor.
6. Set Agenda for Site Visits: The agenda was set to include:
    a. Presentations by prime contractor, USAF and subcontractor
    b. A tour to the manufacturing facilities and access to computer based tools like SAP, process data collection, training records, others.
    c. Breakout session by different groups assigned to assess the different areas including prime contractor, USAF and subcontractor

d. A prime contractor only and USAF only meetings to discuss findings as separate groups.
e. Wrap up meeting with all parties involved to discuss preliminary findings and next steps to complete the assessment.

7. Conduct Assessment: The first step, prior to attending the actual manufacturing facility, was to review the subcontractor self-assessment and determine how the USAF team was going to be divided to cover all areas to be assessed as much as possible. The prime contractor assembled their own team. The day of the assessment the meeting started following the established agenda. After group presentations and questions and answers session, groups were split to start the assessment in different areas of the facility simultaneously. The assessment ended with the wrap up meeting with all parties involved per the established agenda.
8. Prepare Report: The final report was the responsibility of the prime contractor with oversight from the USAF team. It included
    a. The objective and manufacturing process that was assessed
    b. Dates, location, participants of the assessment
    c. Details of what was assessed
    d. Findings, action items, and recommendations based on the prime contractor and USAF oversight of the actual estimated MRL level
    e. A Manufacturing Maturation Plan due to areas not meeting MRL-8
    f. Risk assessment

Table 4

Sample List of Criteria/Questions Applicable to MRL 8

	Question	AN	MR	Thread	Sub
25	Is the industrial capability in place to support Low Rate Initial Production (LRIP)?		8	A - Technology & Industrial Base	A.1 - Technology Transition to Production
39	Have the required manufacturing technology development solutions been validated on a pilot line?		8	A - Technology & Industrial Base	A.2 - Manufacturing Technology Development
57	Have the known producibility issues been resolved and pose no significant risk for Low Rate Initial Production (LRIP)?		8	B - Design	B.1 - Producibility Program
88	Has all the product data essential for system manufacturing been released?		8	B - Design	B.2 - Design Maturity
109	Have cost models been updated with results of the pilot line build?		8	C - Cost & Funding	C.1 - Production Cost Knowledge (Cost modeling)
127	Are costs analyzed using pilot line actuals to ensure target costs are achievable?		8	C - Cost & Funding	C.2 - Cost Analysis
152	Does the cost estimate include investment for Low Rate Initial Production (LRIP) and Full Rate Production (FRP)?		8	C - Cost & Funding	C.3 - Manufacturing Investment Budget
168	Have the materials been proven and validated during Engineering and Manufacturing Development (EMD) as adequate to support Low Rate Initial Production (LRIP)?		8	D - Materials	D.1 - Maturity
188	Have long lead procurements been initiated for Low Rate Initial Production (LRIP)?		8	D - Materials	D.2 - Availability
203	Has an adequate assessment of the critical second and lower tier supply chain been completed?		8	D - Materials	D.3 - Supply Chain Management
226	Have special handling procedures been applied in a pilot line environment?		8	D - Materials	D.4 - Special Handling
241	Have the results of the simulation models been used to improve processes and determine that Low Rate Initial Production (LRIP) requirements can be met?		8	E - Process Capability & Control	E.1 - Modeling & Simulation
259	Have process capability requirements for LRIP been refined based on Pilot Line data?		8	E - Process Capability & Control	E.2 - Manufacturing Process Maturity
273	Have pilot line yield and rate targets been achieved?		8	E - Process Capability & Control	E.3 - Process Yields and Rates
289	Have the program-specific quality plan and Quality Manager been established?		8	F - Quality Management	F.1 - Quality Management including Supplier Quality
309	Are Test and Inspection Plans complete and validated for production units?		8	F - Quality Management	F.2 - Product Quality
322	Have supplier products completed first article inspection?		8	F - Quality Management	F.3 - Supplier Quality Management
348	Have Low Rate Initial Production (LRIP) personnel been trained on the pilot line where possible?		8	G - Mfg Personnel	G.1 - Manufacturing Personnel
360	Have all tooling, test, and inspection equipment been proven on the pilot line?		8	H - Facilities	H.1 - Tooling/ Special Test and Inspection Equipment (STE/SIE)
377	Are manufacturing facilities adequate to begin Low Rate Initial Production (LRIP)?		8	H - Facilities	H.2 - Facilities
398	Have work instructions been finalized?		8	I - Mfg Management	I.1 - Mfg Planning & Scheduling
415	Have material planning systems been proven on the pilot line and are in place for Low Rate Initial Production (LRIP) build?		8	I - Mfg Management	I.2 - Materials Planning

RESULTS AND DISCUSSION

The final MRA report concluded that the assessment demonstrated that the overall manufacturing process for the LRU being reviewed did not fully meet the required level 8 before entering MS-C. Table 5 shows the calculated overall scorecard of MRL-7 after the audit.

Table 5
Overall MRA Score

Thread	Assessed MRL Level	Score Rationale
A-	8	Technology and Industrial Base have been investigated and properly documented
B-	8	Design stable and no short terms plans needed to modify the device
C-	8	Estimated product costs were met. Funding to support production startup and ramp up are allocated accordingly.
D-	8	Materials (Raw Materials, Components, Sub-assemblies and Sub-systems) are properly documented and set in SAP
E-	7	Process Capability & Control adequate. There still are areas of opportunity for process control and production material shelf life control.
F-	7	Quality Management requires improved inspection processes.
G-	7	Mfg. workforce including engineers, technicians, operators, properly trained although additional training is recommended on ESD. Personnel available in the quantity required to support initial and full production.
H-	9	Facilities considered readily available for high volume manufacturing. Maintenance technicians properly trained.
I-	9	Manufacturing management with adequate manufacturing plan, complete work instructions and materials planning.
Overall MRL assessment	7	Several material, process and quality areas have been identified as needing improvement

The report documented the following` areas of improvement and the risk associated.

- Component shelf life control
- Operator self-inspection improvement
- Data collection and analysis
- Electro Static Discharge (ESD)
- Foreign Object Damage (FOD)

A MMP was developed to document and address the areas that do not meet MRL-8. A plan to improve current deficiencies and continue process improvement was developed and will be monitored through regularly scheduled quality assurance meetings. Some of the defect reduction strategy includes:

- Process mapping
- FMEA process
- Process control plan/document
- Gage R&R
- Root cause analysis
    - Cause and effect diagrams
    - 5 Whys
- Corrective action

The risk assessment was completed by the USAF. All risks were considered Low with index ratings between 18 and 20. (See Figure 3.)

The USAF SPO and prime contractor ABC concurred to proceed to MS-C and start LRIP production as scheduled. The action plan for continuous improvements is monitored through regular meetings.

CONCLUSION

The results obtained in this manufacturing assessment provided excellent information to the SPO management to understand the manufacturing maturity at the subcontractor facility. Results showed that the manufacturing levels and risk assessments were identified providing a plan to manage the risk and implementing a plan for improvements.

Even though MRA are not a mandatory requirement for all USAF weapon system projects, it has been recommended as a “good practice” in manufacturing and quality management. It is important to consider, at the time of creating a

request for proposal (RFP) to a contractor, to include the MRA process as a contract element. This effort does not come inexpensive, which is one of the reasons it is not a mandatory process and frequently ignored. But in the long run this process could be beneficial for the life of the program which history shows could be decades long in Military applications.

As a program manager or systems engineer in a USAF program office, acquiring training and knowledge in applying MRA process will provide an excellent tool to determine manufacturing readiness and manage manufacturing risks.

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