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Manufacturing Readiness Levels

techsolutions: Toolkit for DoD Manufacturing Engineers

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A Sign of the Times

By this point, you have undoubtedly noticed the extra "cover" on this issue of the *Quarterly* stating that this will be its last mass-printed issue. Although this is the truth, our publication is not ending – *it's just changing*. Moving forward, the *Quarterly* will be going electronic. The reasons for this change are several, each of which I will discuss in turn, however, I would first like to provide a little background.

The *AMMTIAC Quarterly*, like its predecessor publications from AMPTIAC, MTIAC, NTIAC and earlier, has always been available in a print form – either in a bulletin or journal format. Although AMMTIAC continued the predecessor IAC tradition of providing the *Quarterly* in print, it also started a tradition of its own. Since early 2006, AMMTIAC has released both a print and an electronic issue. The electronic versions provided AMMTIAC the option to publish issues that were more than the standard 16-pages. This was a luxury to our staff, who oftentimes, when preparing the *Quarterly* have had to shorten selected articles so that they would fit within the *Quarterly*'s page limit. In these cases, our electronic version has served as a "Director's Cut", publishing the unabridged version of long articles. Moving strictly to electronic format will allow us to publish extended content on any issue where the content of important articles runs long. Thus, we hope to provide you with greater content in many of our future issues.

So, why are we doing this?

First, our electronic readership has been steadily growing over the past several years, and as such, the receptiveness of our subscriber base to electronic media is growing. Those of you like me, who are old enough to have watched live as Neil Armstrong walked on the moon, grew up before computers became prevalent in our society. Although many of us eventually mastered these tools, we still gravitate naturally towards printed media, as they seem more "real" to us. In fact, many of us who have been in the profession for a few decades are clearly more comfortable with something tangible. I assume your office looks something like mine, with a stack of "reading material" on the corner of your desk or a side table. I certainly hope the *Quarterly* has been part of your stack these past several years. Our new generation of young professionals, however, grew up in the computer age and has been comfortable using such electronic conveniences since before they learned to read. As a result, we have every reason to believe that this trend will continue toward more electronic media being not only acceptable, but also preferable.

Second, like any responsible government entity, IACs must exercise some level of environmental consciousness in an active, but measured way that is reasonable and makes sense. At present, we print over 19,000 copies of the quarterly for each issue – this adds up to a lot of paper. As we go more "paperless" in our work environments, it makes sense to observe practices that are commensurate with that philosophy in all aspects of our operation.

Lastly, AMMTIAC is doing its part to meet Secretary Gates' call for increased efficiencies within the DoD. Part of those savings will come through ending our free print service. Printing and mailing newsletters to more than 19,000 readers four times a year is an expensive undertaking. Since our electronic issues provide the same content as our printed version, we are able to continue serving our user community at the same level of quality and service, but at a significantly reduced cost.

If you have not already done so, I encourage you to follow the directions on this issue's outer jacket to sign up for the electronic newsletter. We would not want you to miss future issues. Like the present electronic editions of the *Quarterly*, the coming issues will be no different. Notification of their release will be sent via email. This email will provide an overview of the articles and direct you to our website, http://ammtiac.alionscience.com, where the *Quarterly* will be available for download in .pdf format. These issues are print-ready, and with a color printer and Adobe Reader, you should be able to create your own de facto print issue if preferred.

We do, however, recognize that there is still a good fraction of you who would prefer to continue receiving a print copy. If you would be interested, we encourage you to take our brief online survey such that we can assess alternative avenues to continue providing print service on a more limited basis in the near future. On behalf of the entire AMMTIAC staff, we thank you for your continued interest and support these past years, and as we move forward into this new world. We hope that you continue to read the *Quarterly* and provide us with as much feedback as possible.

Chris Grethlein, Deputy Director

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The cover features a photograph of Lockheed Martin's C-130 Hercules production line, taken in their Marietta, GA plant. (Photo courtesy of Peter Simmons, Lockheed Martin, Marietta, GA)

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Manufacturing Readiness Levels

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INTRODUCTION

The Importance of Manufacturing Maturity

Department of Defense (DoD) weapon systems have been rapidly increasing in complexity for the past 50 years. New materials and technologies are continually developed and, with them, new production methods. Although the material and technology developments have been successful in most instances, the development of mature manufacturing processes has notably lagged in many programs. This has resulted in the production of unreliable components and, ultimately, systems.

First noticed in 2000, this trend has been gaining increased attention. In the 2006 annual review of the major defense acquisition programs (MDAPs)*, it was found that of the 62 MDAPs only 10% were collecting manufacturing process data and 0% were in control of their manufacturing process, showing a significant lack of manufacturing maturity.[1] More recently, during the 2009 annual MDAP review, covering design, technology, and manufacturing maturity by the General Accountability Office (GAO), a lack of manufacturing maturity was found in almost every program. This lack of maturity in all three areas resulted in $300 billion (FY 2010 dollars) of cost overruns and production schedules that were an average 22 months behind the original estimates.[2, 3]

Since the early release of the GAO's findings, the DoD has increased the attention given to assessing manufacturing maturity during the key reviews within the acquisition process. In the most current revision of the DoD Instruction (DoDI) 5000.02, published in December 2008, the DoD addresses the need to consider manufacturing earlier in the Defense Acquisition Life Cycle. The Defense Acquisition Life Cycle is a series of weapon systems life cycle phases, shown in Figure 1. To advance from one phase to the next within the Defense Acquisition Life Cycle, a milestone (A, B, or C) review must be completed, presided over by a Milestone Decision Authority (MDA). The MDA decides if pre-determined entrance criteria have been met prior to granting approval to proceed. From a manufacturing standpoint, the MDA must be armed with complete knowledge of all manufacturing risks and the magnitude of those risks, so that they can take them into account during the decision process.

The December 2008 revision of DoDI 5000.02 also included a name change to place an added emphasis on the importance of manufacturing maturity. The primary development phase of the Defense Acquisition Life Cycle, termed System Design and Development, has been renamed Engineering and Manufacturing Development (EMD) to recognize that manufacturing development efforts must occur concurrently with product design. During EMD, DoD Instruction 5000.02 requires that a weapon system be designed for producibility. In addition, critical manufacturing processes must be matured, and the manufacturing process demonstrated in a pilot line environment. To enter the Low Rate Initial Production (LRIP) phase, which includes delivery of the initial 10% of the total expected quantities, a program must not have any significant manufacturing risks. To begin the Full Rate Production (FRP) phase, in which the remaining quantities are produced, the program must demonstrate manufacturing process control. The term control is used to describe a statistically stable manufacturing process in which the output is predictable.

To ensure proper advancement through the phases of the Defense Acquisition Life Cycle and that manufacturing maturity is achieved, Manufacturing Readiness Levels (MRLs) were developed. MRLs are an excellent tool for evaluating the Defense Acquisition Life Cycle criteria and identifying manufacturing risks.

The JDMTP
The Joint Defense Manufacturing Technology Panel (JDMTP) was chartered by the Director of Defense Research and Engineering (DDR&E). Consisting of senior technology managers from the Army, Navy, Air Force, Defense Logistics Agency (DLA), and Missile Defense Agency (MDA), the JDMTP's purpose is to develop joint ManTech program strategies and promote the Defense-wide application of ManTech.

MANUFACTURING READINESS LEVELS: AN OVERVIEW

Designed to mirror Technology Readiness Levels (TRLs), MRLs were created and promoted by the DoD's Manufacturing Technology (ManTech) organization in partnership with the Joint Defense Manufacturing Technology Panel (JDMTP).

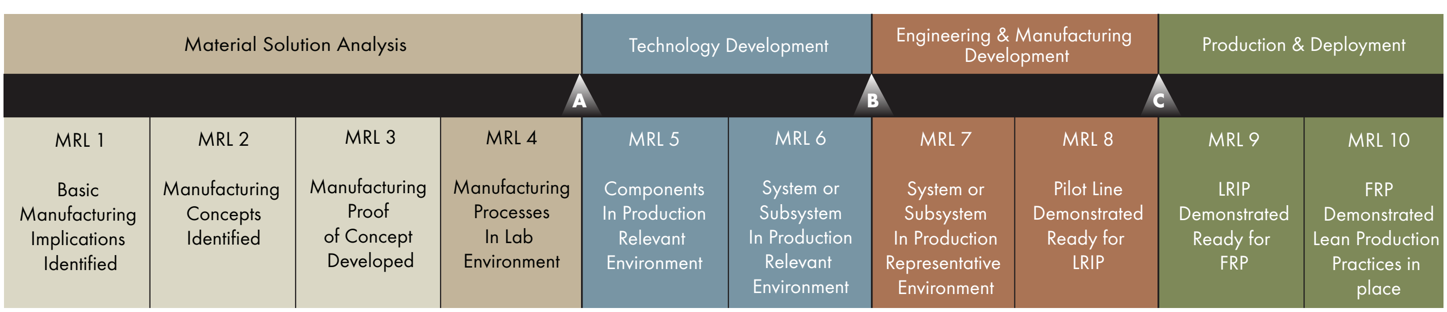

Figure 1. An excerpt of the Defense Acquisition Life Cycle (top) with the MRL expectations at each phase and milestone (bottom).

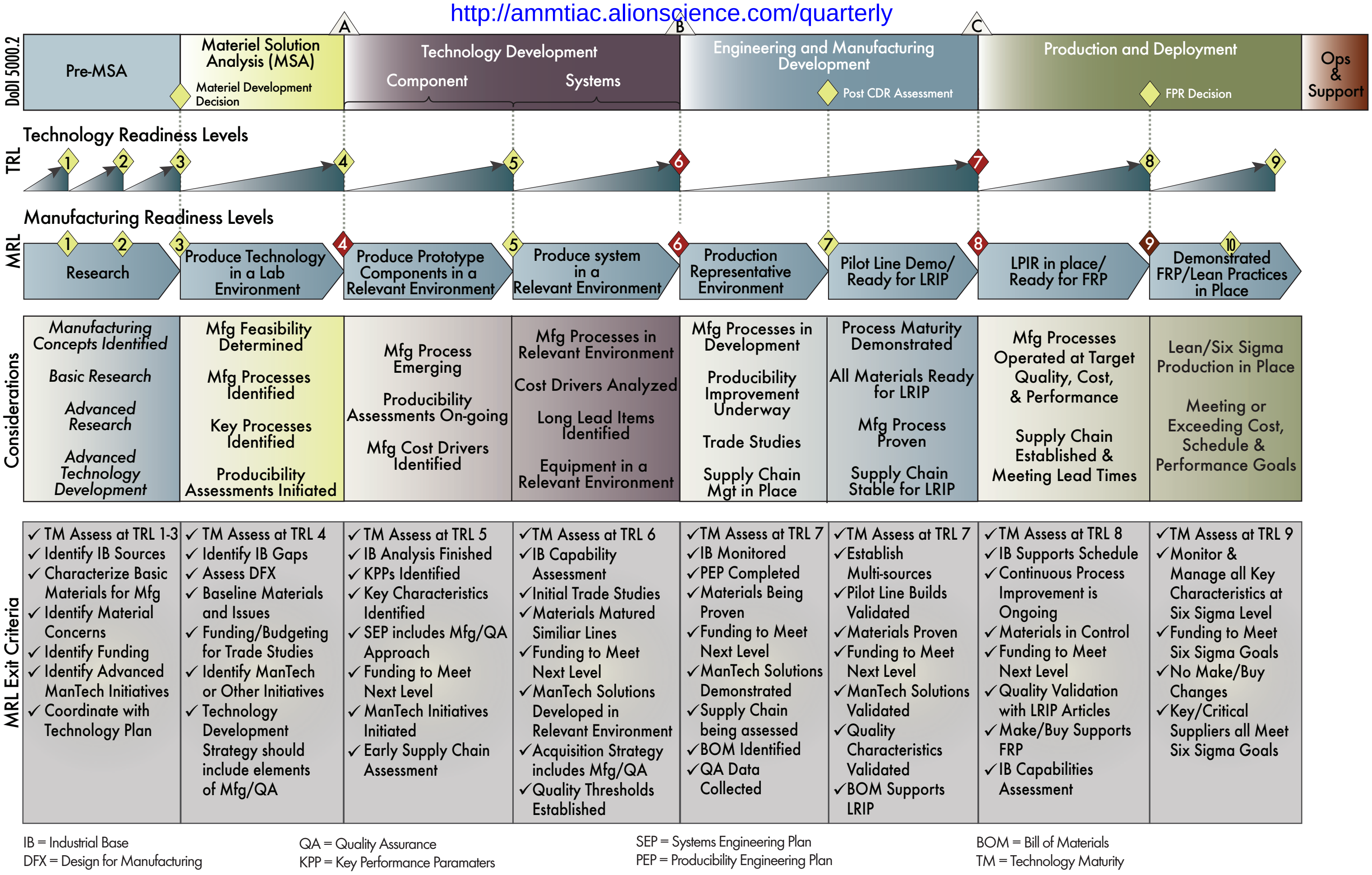

Figure 2. **Illustration of the relationship between MRLs, the Defense Acquisition Life Cycle, as defined in DoD Instruction 5000.2, and TRLs. This chart also lists the considerations and exit criteria for each MRL.[4]**

TRLs are well-understood concepts within the DoD that measure the maturity of critical technology elements using a numerical scale from one to nine: a one denotes a basic research technology and a nine an operationally proven technology. The numerical scale provides a universal language that can be used to communicate current maturity and future expectations. Figure 2 illustrates the relationship between MRLs, TRLs, and the Defense Acquisition Life Cycle.

The MRL Working Group, which consists of representatives from each of the DoD Services, the Missile Defense Agency, and the defense industry, was established by the JDMTP to develop detailed definitions and criteria for each of the MRLs and to develop an MRL assessment process. The definitions and criteria were developed using industry and defense proven best manufacturing, engineering, and management practices. To ensure that industry concerns were addressed, several hands-on workshops for both large and small companies were held to help develop the MRL criteria and assessment process.

MRLs are intended to set expectations for a program at each phase of the Defense Acquisition Life Cycle. If a program does not reach its target MRL, a Manufacturing Maturation Plan (i.e., risk reduction plan) must be developed. It is important that MRLs not be viewed as program go or no-go criteria. Doing this would apply unnecessary pressure to the assessment team and inhibit the ability of the team to provide an honest evaluation of the risk(s).

MRL determinations are made through the evaluation of nine topic areas or threads. These threads (Figure 3) are similar to the topics typically addressed during a Production Readiness Review (PRR). PRRs are one-time events held prior to Milestone C. They have been used by the DoD for several years to determine if a program is ready to progress into the Production phase of the Defense Acquisition Life Cycle. MRL assessments, on the other hand, are conducted throughout the acquisition cycle.

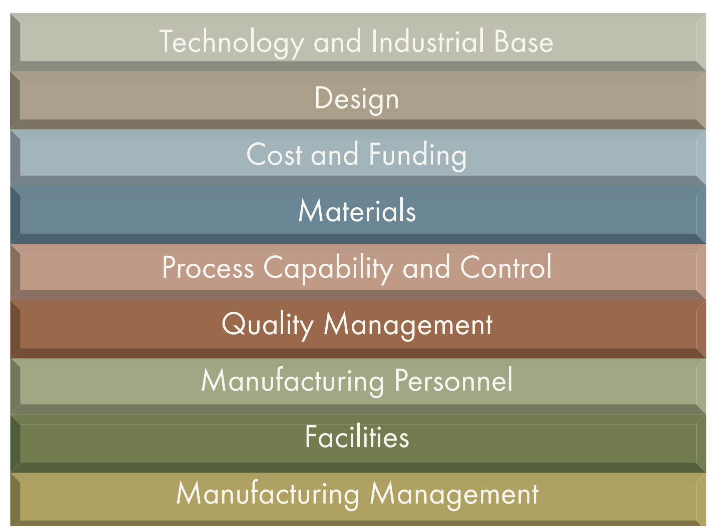

Figure 3. **The nine MRL threads.**

With an MRL assessment, the threads are arranged in a matrix. Objective criteria are provided for each thread and level to reflect the growing expectation of maturity as the program progresses through its life cycle. An excerpt of the MRL matrix is shown in Figure 4. During the early MRL phases, manufacturing feasibility is the only expectation. As a program progresses through development, the MRL criteria become more stringent and production representative manufacturing processes are anticipated. At the finish

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DoD Manufacturing Readiness Levels (MRLs)						
Acquisition Phase			**Engineering & Mfg Development (EMD)**		**Low-Rate Initial Production (LRIP)**	**Full-Rate Production (FRP)**
Technical Reviews			**CDR**	**PRR/SVR** C	**FCA**	FRP
Thread	**Sub-Thread**		**MRL 7**	**MRL 8**	**MRL 9**	**MRL 10**
	Technology Maturity		Should be assessed at TRL 7	Should be assessed at TRL 7	Should be assessed at TRL 9	Should be assessed at TRL 9
A - Technology & Industrial Base	A.1 - Technology Transition to Production	1	Industrial capability to support production has been analyzed. Sole/single/foreign sources stability is assessed/monitored. Developing potential alternate sources as necessary.	Industrial Capability Assessment (ICA) for MS C has been completed. Industrial capability is in place to support LRIP. Sources are available, multi-sourcing where cost-effective or necessary to mitigate risk.	Industrial capability is in place to support start of FRP.	Industrial capability supports FRP. Industrial capability assessed to support modifications, upgrades, surge and other potential manufacturing requirements.
	A.2 - Manufacturing Technology Development	6	Manufacturing technology efforts continuing. Required manufacturing technology development solutions demonstrated in a production representative environment.	Primary manufacturing technology efforts concluding, and some improvement efforts continuing. Required manufacturing technology solutions validated on a pilot line.	Manufacturing technology process improvements efforts initiated for FRP.	Manufacturing technology continuous process improvements ongoing.
	B.1 - Productibility Program		Detailed producibility trade studies using knowledge of key design characteristics and related...	Producibility improvements implemented on system. Known producibility issues have been resolved and...	Prior producibility improvements analyzed for effectiveness during LRIP. Producibility issues/risks...	Design producibility improvements demonstrated in FRP. Process producibility ...

Figure 4. MRL matrix excerpt.

of the EMD phase, programs should make use of the same tooling, test equipment, workforce, work instructions, and methods that will be used during the production phases.

MANUFACTURING READINESS ASSESSMENTS

To conduct an MRL-based review, also known as a manufacturing readiness assessment (MRA), knowledgeable personnel are required to apply the objective criteria in the MRL matrix to the manufacturing process of interest and to determine its maturity. These reviews are typically conducted by small teams of two to six manufacturing, quality, and systems engineering experts. At most supplier locations, the reviews last for one or two days, depending upon the nature and complexity of the manufacturing process being reviewed.

Manufacturing readiness assessments (MRAs) are straightforward. The most challenging phase of the assessment is the up-front planning, which determines the scope and extent of the review. The government-contractor team must select the components, suppliers, or technologies that warrant a review. Often, the magnitude of the potential manufacturing risks determines whether or not a review should be conducted. A list of questions has been developed for the team to use in determining the potential risks for a given component or supplier. These questions are available in the *MRL Deskbook*.

Unfortunately, in many cases, cost constraints limit the situations in which reviews are conducted. Although each individual review is not costly, the preparation, execution, and follow-up at the various suppliers may be cost-prohibitive, especially if these activities have not been budgeted for during contract negotiations. The contractual arrangements between the government and the prime contractor, along with those between the prime contractor and the lower tier suppliers, can have a major impact on whether this will be an easy issue to solve. Contractors operating under a cost-type contract usually have more flexibility in the number of suppliers they visit. Conversely, the contractors operating under a fixed price contract may not have that flexibility. Therefore, it is critical that MRL assessments be included in Request for Proposals and in the final, contractual Statement of Work (SOW), which should include a clear definition of the methodology and scope of the assessments. An MRL plan documenting this information can be included as an attachment to the contract.

Once an assessment is complete and an MRL number has been assigned, the team must develop Manufacturing Maturation Plans (MMPs) for any threads that were not scored at the target MRL. The MMPs need to identify the target and actual MRLs, the reason(s) for the shortfall(s), and an action plan for achieving the desired MRL that includes a schedule and list of needed resources.

MRLS AND THE AERONAUTICAL SYSTEMS CENTER

The Aeronautical Systems Center (ASC), a division of the Air Force's Materiel Command, has been required by its Commander, Lieutenant General Thomas J. Owen, to implement MRLs prior to reaching a major milestone of the Defense Acquisition Life Cycle. As a result, ASC has conducted several MRL assessments and has had a variety of experiences pertaining to MRAs. The common trend has been success – success in conducting reviews, in identifying risks that might have otherwise been missed, and in elevating the visibility of manufacturing considerations.

The MRL Deskbook

The *MRL Deskbook* was developed by the MRL Working Group as a guide for anyone implementing MRLs. The deskbook includes MRL definitions, the relationships of the MRLs to the acquisition life cycle, the steps in the MRL assessment process, and options for including MRLs in requests for proposals and contracts. It is available at www.dodmrl.com and is updated annually, or as needed, by the MRL Working Group to incorporate lessons learned and best practices.

MRL Concerns and Remedies

Although successful overall, some programs have resisted MRAs, arguing that MRLs do not apply to them because their program is different. To address this concern, the ASC Engineering Directorate, the MRL process owner at ASC, has worked hand-in-hand with the programs to tailor the MRA to their unique situations. Once the programs understood the potential benefits of MRLs and the flexibility they had in conducting the MRL assessments, they were willing to make them work. ASC's Engineering Directorate attempts to provide as much flexibility as possible without losing sight of the ultimate goal, which is to identify manufacturing risks using the objective MRL criteria.

Unique program situations have led to several different types of assessments. The traditional approach is the on-site review, much like a PRR. However, programs have also conducted desk-audits, which are assessments performed entirely by the Air Force with no visits to the contractors. ASC conducts assessments in this manner only in truly unique situations where no contractor involvement is possible (i.e., when there is no contract vehicle in place to obtain contractor participation). In situations like this, the Air Force must rely upon information generated earlier in the program or on information gleaned from market research or industrial base analyses. When executed in this manner, the assessments are not as thorough as one with contractor involvement, but at a minimum, the manufacturing issues are being considered and analyzed.

Another approach is to conduct MRL assessments during competitive acquisitions. If manufacturing issues could be a discriminator during source selections, then the offerors are asked to perform an MRL self-assessment and discuss the results in their proposals. The government's Source Selection Evaluation Team is then responsible for evaluating the offerors' assessments and for asking follow-up questions as needed to gain additional insight. This information is used to help weigh the manufacturing risks among the offerors.

Concern has also been expressed as to whether there are enough trained personnel to conduct MRL assessments effectively. Although the basic answer is yes, each Service and Acquisition Center is manned differently. To date, ASC has been fortunate enough to have sufficient resources to conduct MRL assessments. This should be the case for the near future as well. However, as more programs start implementing MRLs and conducting reviews at numerous suppliers, the demand for trained manufacturing engineers may create resource issues.

Another common concern is the honesty of the MRL assessments, especially the self-assessments conducted by the contractors. ASC has found, however, that their industry partners have done very thorough and honest assessments. For one large aircraft modernization program, the Air Force team knew that a lower tier supplier would not be at the target MRL of 8. The government team members were concerned that either the supplier would try to project a false picture of their maturity or the prime contractor would argue for a higher rating. Either way, the Air Force team went into the assessment expecting significant confrontation. To the delight of the Air Force, the supplier presented their self-assessment openly and honestly, rating themselves at MRL 6. The prime contractor readily agreed. As a result, the team was able to spend more time effectively working problem resolutions rather than arguing over the rating.

Lessons Learned

Training has emerged as a key lesson learned. This includes training for the program office, the prime contractor, and all suppliers that will be hosting an assessment. ASC has found that individuals and organizations (both within the government and in industry) not familiar with MRLs may be reluctant to use them. A large portion of this reluctance stems from a lack of understanding about what MRLs are and how they are used. Once organizations have received training (either in-depth or at overview level), they are much more accepting and often become avid supporters of the concept. Training materials are available from multiple sources, including the www.dodmrl.com website. Nevertheless, the best resources are the Services' MRL Focal Points. ASC has even provided on-site training for the lower tier suppliers. It was found that the improved understanding and buy-in was well worth the investment in time and travel.

ASC has also recognized that contractor self-assessments are a valuable part of the process. The government team provides contractors with the MRL matrix (or related list of questions) and asks them to develop and provide responses prior to the team arriving for the on-site review. In addition to familiarizing the assessment team with the contractor's products and processes, the self-assessment allows for a more effective discussion of the issues because all parties can be better prepared to address the areas of weakness.

ASC Success Stories

There have been several Air Force success stories relating to the implementation of MRLs. One specific success story includes an Air Force bomber modification program. The program office personnel, in conjunction with the prime contractor, assessed a dozen key suppliers and identified numerous risk areas that required Manufacturing Maturation Plans. The identified risks ranged from product oriented actions (design changes and diminishing manufacturing source issues) to factory process improvements (quality and production control systems). The program office was thankful they had conducted the assessments and firmly believed that, had the MRL process not been in place, many of these risks would not have surfaced until the program started production, resulting in cost and schedule impacts.

ASC has found that MRL reviews can also provide benefits to the prime contractors and suppliers. In some instances, where there is limited government program office manning, the government engineers and program managers may not be aware of issues at lower tier suppliers. In the case of another Air Force bomber modification program, the MRL assessment revealed diminishing manufacturing source issues at suppliers for which the government had to take action to resolve. The contractors were pleased to be able to elevate the issue to the government customer. In another example, the MRL assessment for a piece of personal protection equipment identified the need for additional manufacturing technology development. This finding led the government to allocate additional funding for the contractor to improve manufacturing process yields, which will improve schedule confidence and reduce cost.

ACHIEVING PROGRESS

MRLs can be viewed as a snapshot of manufacturing maturity at a moment in time, as a final exam, or even as a midcourse quiz. Very few students can take a test without studying and expect to pass with flying colors. Just like studying for a test, preparation is the key to successfully achieving target MRLs. Preparation involves much more than just getting ready for the review itself. It involves activities and behaviors throughout the life cycle of a weapon system that continually mature the manufacturing processes and systems.

Since MRLs are primarily criteria and expectations for program phases and milestones, they do not directly describe the on-going practices that need to be implemented throughout a program to ensure success. The MIL-HDBK-896, *Manufacturing and Quality Program*, was written specifically to complement the MRLs by describing a set of best manufacturing and quality practices that will enable the achievement of target MRLs. The handbook organizes best practices by the threads of the MRL matrix. For each thread, the handbook provides suggested tools, techniques, and practices that will enable successful progression through the Manufacturing Readiness Levels.

Using the design thread as an example, MIL-HDBK-896 recommends the implementation of a formal producibility program, the identification of key characteristics, and the consideration of production process capabilities during design trade studies. By properly applying these practices, the program has an excellent chance of meeting the design thread criteria during an MRL assessment.

THE FUTURE OF MRLS

MRLs are emerging as the tool of choice for assessing manufacturing maturity. Their usage will continue to grow as more government customers become familiar with them and begin to contractually require MRAs. Once an organization uses MRLs, they realize how easy MRLs are to apply and the extensive benefits that MRLs bring. The Air Force's Aeronautical Systems Center and Air Armament Center require that MRL assessments be conducted prior to major program milestones so that decision makers are well aware of manufacturing risks. More defense industry partners are gaining experience with MRLs and are incorporating them into their own internal corporate practices.

The MRL Working Group continues to refine the MRL criteria matrix and to improve the MRL assessment process. Although changes are very minor at this point, the team practices continuous improvement to ensure the best possible tools are available by incorporating the latest lessons learned into the criteria and process. The group plans to continue hosting annual workshops with government and industry to assess progress and update the core documents.

The GAO studied the adoption of MRLs in both the government and industry and reported their results in GAO-10-439, *DoD Can Achieve Better Outcomes by Standardizing the Way Manufacturing Risks Are Managed*. They found that MRLs "offer the potential for the DoD to achieve savings and efficiencies in developing and acquiring weapon systems" and that "commercial firms have adopted MRLs or are employing similar criteria in their product development processes."[5] The GAO recommended that the DoD use MRLs for assessing manufacturing readiness across DoD programs. The Office of the Secretary of Defense (OSD) has been considering an MRL policy for all of the Services. A clear message from OSD on the adoption of MRLs would cement MRLs as the Standard Operating Procedure across the defense industry for assessing manufacturing maturity.

SUMMARY

In ASC's experience, MRLs are clearly accomplishing the purpose for which they were designed, bringing more attention to manufacturing issues. Mr. Frank Grimsley, ASC's Technical Director for the Systems Engineering Division, reports that, "The MRL assessment process at ASC identifies potential risks to production early and gives the US Air Force the ability to hit the ground running in solving those risk areas before they impact cost or schedule. It makes the USAF a much smarter customer."

ACKNOWLEDGEMENTS

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REFERENCES

*An MDAP is a DoD acquisition program that is not highly sensitive or classified. MDAPs are designated or estimated by the Secretary of Defense to require an eventual total expenditure for research, development, test, and evaluation of more than $365,000,000 (updated to FY 2000 constant dollars), or an eventual total expenditure for procurement of more than $2,190,000,000 (updated to FY 2000 constant dollars).[6]

[1] "Defense Acquisitions: Assessments of Selected Weapon Programs," United States Government Accountability Office, GAO Report No. GAO-07-406SP, March 2007.
[2] Sullivan, M.J., "Defense Acquisitions: Assessments of Selected Weapon Programs," United States Government Accountability Office, GAO Report No. GAO-10-388SP, March 2010, p. 2.
[3] Sullivan, M.J., "Defense Acquisitions: Assessments of Selected Weapon Programs," United States Government Accountability Office, GAO Report No. GAO-09-326SP, March 2009, p. 7.
[4] "Manufacturing Readiness Levels," http://www.dodmrl.com/MRL_Overview_Chart.pdf, accessed September 2010.
[5] Sullivan, M., "Best Practices: DoD Can Achieve Better Outcomes by Standardizing the Way Manufacturing Risks Are Managed," United States Government Accountability Office, GAO Report No. GAO-10-439, April 2010, pp. 28 & 43.
[6] Defense Acquisition University, "Major Defense Acquisition Programs (MDAP)," https://acc.dau.mil/CommunityBrowser.aspx?id=141955&lang=en-US, accessed September 2010.

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RESOURCES

The website www.dodmrl.com is available for anyone who would like more information on MRLs. It serves as a "one-stop shopping" repository for MRL resources and contains the *MRL Deskbook*, the MRL matrix, brief training tutorials, and two automated tools to help in conducting assessments.

The MRA Tool is an Excel-based program that facilitates evaluation and documentation of MRL assessments by multiple evaluators. The MRL ASSIST program provides questions to supplement the MRL matrix and help evaluators gain additional insight into manufacturing evaluation areas.

The Air Force Institute of Technology has developed a course that allows students hands-on experience in conducting a simulated MRL assessment. This course, designated SYS 213: "*Manufacturing Readiness Assessments,*" is open to all branches of DoD and industry, although a minimal fee may be required for contractors.

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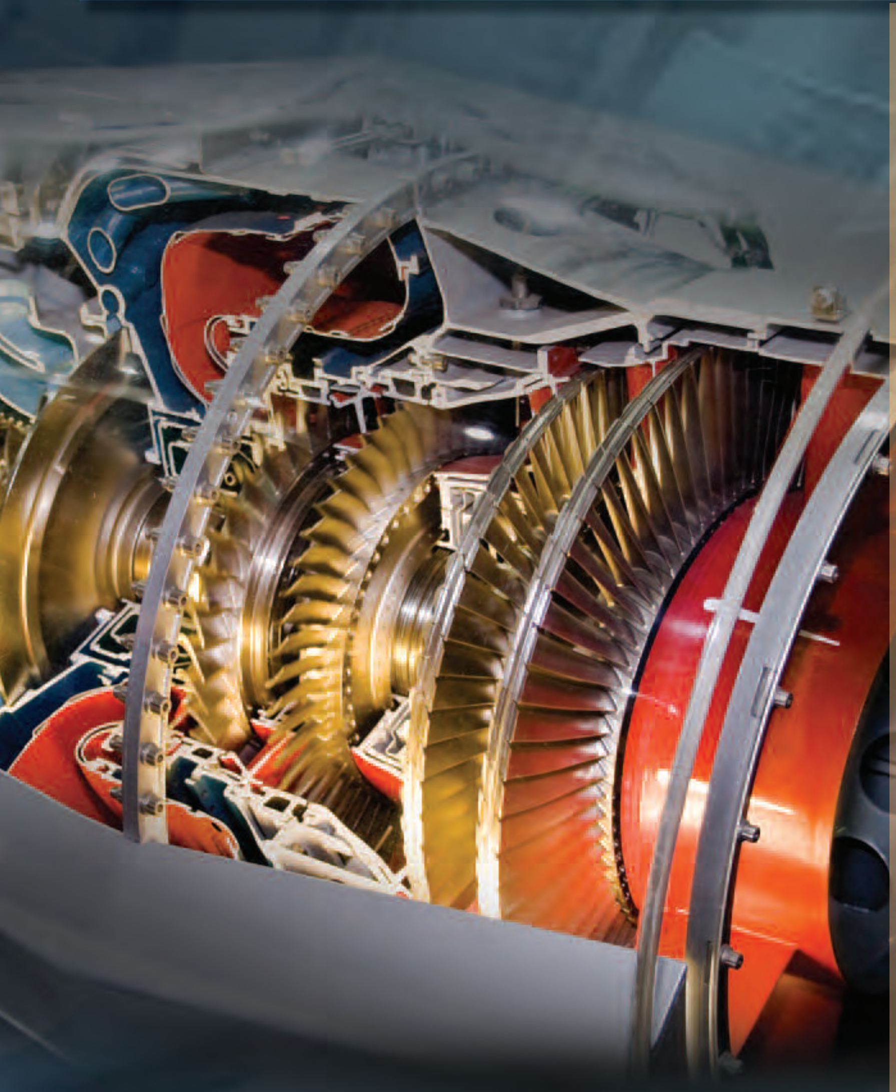

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Toolkit for DoD Manufacturing Engineers

INTRODUCTION

The Department of Defense (DoD), more often than not, requires that its products be held to elevated quality and performance standards, especially when compared to commercial products. These higher expectations lead to increased scrutiny, and subsequently, significant differences between the production cycles for DoD weapons systems and commercial products. Thus, to produce weapon systems and their components for the DoD, manufacturing engineers must have specialized and superior manufacturing knowledge.

In a commercial manufacturing setting, each manufacturer has its own set of production guidelines. These guidelines set the policies and standard operating procedures for material sourcing, supply chain management, product assembly, and quality. Likewise, the DoD has its own set of agency-wide guidelines for the manufacture of weapon systems. These guidelines coincide with the phases of the Defense Acquisition Life Cycle. However, because the Defense Acquisition Life Cycle is complex, there are numerous guidelines to follow.

This sizeable quantity of guidelines can pose challenges to manufacturing engineers as they work to remain up-to-date with the latest updates and changes. To mitigate hiccups in the transmission of this information, several resources have been developed to aid in the dissemination of the most current rules and regulations, to share lessons learned, and to foster collaboration between manufacturing groups within the DoD.

This article provides an overview of the resources available for DoD manufacturing engineers. These resources can be utilized to aid in the delivery of weapon systems that meet performance and quality requirements on schedule and without cost overruns.

DOD REGULATIONS

DoD Instruction (DoDI) 5000.02 provides a simplified, flexible management framework for translating capability needs and technology opportunities into stable, affordable, and well-managed acquisition programs. Moreover, it details the proper operation of the Defense Acquisition Life Cycle system and provides detail for program managers, explaining how they should be implementing this directive.[1]

In this instruction, the DoD Defense Acquisition Life Cycle framework is presented. Furthermore, each Service is assigned key responsibilities, the majority of which are necessary for carrying out the tasks related to DoD weapon system development and production. Most importantly, the DoDI 5000.02 framework places increased importance on developing mature manufacturing processes early in the weapon system development process. To do this, the framework requires manufacturing readiness assessments as an exit criterion for three different acquisition phases. The System Development and Demonstration (SDD) phase of the Defense Acquisition Life Cycle was renamed Engineering and Manufacturing Development (EMD) in this instruction as well.[2]

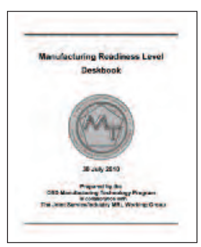
GUIDING DOCUMENTS

Several publications have been created and made available to assist manufacturing engineers in meeting the manufacturing-related requirements set forth in DoDI 5000.02. These documents cover process design, manufacturing maturity, part quality, obsolescence, and process improvements.

MIL-HDBK-896

The DoD Handbook *Manufacturing and Quality Program* (MIL-HDBK-896) is a collection of best practices for weapon system production and product quality. MIL-HDBK-896 was created by the Manufacturing and Quality Branch of the Air Force's Aeronautical Systems Center Engineering Directorate. This branch is also responsible for maintaining the handbook and ensuring that all information is up-to-date.

The 11-page MIL-HDBK-896 is intended for use across the services, in parallel with the guidance provided by the DoD's *Manufacturing Readiness Level Deskbook* and the Air Force's *Manufacturing Development Guide*. It provides detailed guidelines for the performance of manufacturing readiness assessments. In addition, this handbook defines the production and quality-related terms commonly used in the DoD.[3]



Manufacturing Readiness Level Deskbook

The DoD *Manufacturing Readiness Level Deskbook* was developed by the Joint Defense Manufacturing Technology Panel's (JDMTP's) Manufacturing Readiness Level (MRL) Working Group. This deskbook is a comprehensive resource that discusses manufacturing readiness levels (MRLs) and manufacturing readiness assessments (MRAs).

The *MRL Deskbook* provides detailed definitions for each MRL. It also presents the MRL threads and sub-threads and provides detailed instructions for incorporating MRLs and MRAs into source selection criteria as well as other facets of the government proposal process. Since the *MRL Deskbook* is updated on an annual basis, or as needed, it is continuously evolving to best support DoD manufacturing efforts.

Process maturity is critical to the success of a weapon system. To address readiness in pre-weapon system acquisitions, the *MRL Deskbook* provides guidance to ensure that manufacturing-related considerations are the focus during the Materiel Solution Analysis and Technology Development phases of the Defense Acquisition Life Cycle. In addition, best practices are provided to address manufacturing maturity during the EMD and the Production and Deployment phases of weapon system acquisition.

Table 1. The *Manufacturing Development Guide* best practice focus areas.

Best Practice Area
Manufacturing Capability Assessment and Risk Management
Production Cost Modeling
Key Suppliers
Key Characteristics and Processes
Variability Reduction
Virtual Manufacturing
Design Trade Studies
Process Failure Modes Effects and Criticality Analysis
Product and Process Validation
Manufacturing Process Control and Continuous Improvement
Factory Efficiency
Technology Obsolescence and Diminishing Manufacturing Sources

One of the main methods for evaluating process maturity is the MRA. MRAs are employed to measure the maturity of a manufacturing process, playing an important role prior to major Milestone Reviews and acquisition decisions. The *MRL Deskbook* further describes how to develop the scope of an MRA, prepare the contractor for the MRA, and carry out the MRA. The information gathered during an MRA is used to identify manufacturing risks and develop risk management and manufacturing maturation plans (MMPs).

The DoD *Manufacturing Readiness Level Deskbook* can be accessed online through the DoD Manufacturing Readiness Level resource website at http://www.dodmrl.org/ or http://www.dodmrl.com.[4]

Manufacturing Development Guide

The Air Force *Manufacturing Development Guide (MDG)* provides guidance for improving Air Force weapon system acquisition. However, much of the information can be utilized by non-Air Force organizations interested in operational improvement.[5] This guide provides tools to ensure that important design and manufacturing decisions are made early in the development process. Further, the *MDG* details the positive impacts that result from making manufacturing decisions early in the acquisition process, specifically those related to the financial and contractual considerations. The *MDG* presents the defense industry with quality-related tools and techniques that have produced positive results in the commercial manufacturing industry.

The best practices and lessons learned, that relate to these industry-adopted tools and techniques, are described in Chapter 6 of the *MDG*. Rationale for each tool and technique is provided as well to significantly reduce the potential for misinterpretation during the implementation of these practices into the Integrated Product and Process Development (IPPD) process. Table 1 lists the *MDG*'s best practice focus areas. The *MDG* also defines the roles that manufacturing engineers, for the contractor and the government, play in developing the weapon system and requisite production process. A sample of the contractor and government manufacturing engineers' responsibilities can be found in Table 2.[5]

Table 2. Example of Tasks and Responsibilities for manufacturing engineers during IPPD. [5]

Responsible for Task	Task Description
Government Manufacturing Engineer	Participate in trade studies
	Develop and refine Production Cost Model
	Initiate mapping of Key Characteristics & Processes
	Establish data collection for process capability requirements
	Initiate process development as required
	Participate in manufacturing capability and risk assessments
	Integrate suppliers into production process
	Develop and validate production plan
	Implement efforts to reduce variability
	Implement efforts to prevent defects
Contractor Manufacturing Engineer	Monitor process variation
	Develop plan for implementing process/product changes
	Implement continuous process improvement techniques (Lean Manufacturing, Six Sigma)
	Maintain Production Cost Model

DMSMS Guidebook

The DoD *Diminishing Manufacturing Sources and Material Shortages* (DMSMS): *A Guidebook of Best Practices and Tools for Implementing a DMSMS Management Program* (Report # SD-22) is a comprehensive resource that aids in the management of DMSMS. This guidebook was compiled and published by the Defense Standardization Program Office (DSPO). DMSMS relates to the loss of a source for a material or item, which in most instances surfaces when a supplier discontinues the production of a particular product or when the product becomes unavailable. Written for program managers, the DMSMS guidebook contains methods for managing and mitigating part obsolescence issues common within the DoD, specifically in the areas of electronic, electrical, and mechanical parts. These methods were derived from the best practices identified by several DoD organizations.

The DMSMS guidebook defines a proactive DMSMS man-

Table 3. **DMSMS Intensity Levels.[6]**

Intensity Level	Description
Level 1	Current practices for resolving identified obsolescence risks are satisfactory.
Level 2	Current practices for resolving future obsolescence risks are satisfactory.
Level 3	Current practices for mitigating obsolescence risks are adequate for situation where likelihood of opportunity to reduce total ownership costs is high.
Level 4	Current practices implemented during conceptual design phase continue through the weapon system sustainment cycle.

agement process, which can be used to build an effective DMSMS Program. It also defines the DMSMS support metrics that are used to measure the effectiveness of a proactive DMSMS Program, promotes cost-effective supply chain management integrity through DMSMS problem resolution at the lowest level, and promotes the exercise of best practices throughout the DMSMS management cycle.[6]

The four levels of DMSMS program intensity are described in Table 3. Table 4 provides the mitigation practices for each intensity level. Additional DMSMS program guidance is provided through tools in the form of DMSMS-related documents, web-based resources, and design interface assessment criteria.

The *DMSMS* guidebook can be accessed electronically through the DMSMS Sharing Portal at http://www.dmsms.org/.

DoD CPIT Guidebook

The DoD's *Continuous Process Improvement Transformation Guidebook (CPIT Guidebook)* was developed under an initiative set forth by the former Under Secretary of Defense, Gerald England. Continuous process improvement (CPI) is a process that ensures a continued improvement in an organization's performance. The key to CPI success is consistent and sustainable leadership and guidance. When considering CPI methodologies, any organization that delivers services or produces products should be viewed as a transformation mechanism.[7]

The *CPIT Guidebook* provides a method for improving DoD operational performance. In order for the continuous process improvement (CPI) method to produce lasting results, a culture of continuous improvement needs to be implemented. The *CPIT Guidebook* outlines four integral components that are needed for lasting continuous improvement efforts. These needed components are: a broad, structured CPI implementation method; focus on CPI implementation within a structure of goals that are aligned to a warfighter-driven, outcome-based metric; emphasis on the management and integration of CPI projects; and methods for determining how well projects and organizations progress with CPI initiatives, training, and certification.[8]

Upon CPI process initiation, customer requirements and organizational resources are transformed into goods, services, and business outcomes for the customer's benefit, known as process completion. The results can be tangible or knowledge-based. While

Table 4. **DMSMS Mitigation Practices.[6]**

Intensity Level 1	Intensity Level 2	Intensity Level 3	Intensity Level 4
DMSMS program established and funded DMT formed DMT trained in • DMSMS fundamentals and • DMSMS for executives DMSMS program plan written and approved Complete BOM developed with periodic reviews planned to keep it current Solutions to near-term obsolescence problems implemented For new acquisitions, DMSMS tasking and data byproducts inserted in the development, production, or support contracts	All level 1 practices implemented BOM processed through a predictive tool Results of predictive tool output analyzed DMSMS solution database established Budget established to fund future obsolescence solutions Website established Method established to prioritize LRUs/WRAs for DMSMS risk	All Level 2 Practices implemented DMSMS life-cycle costs and cost avoidance estimates developed DMT trained • DMSMS essentials, • DMSMS case studies, and • advanced DMSMS Funding shortfall and impact identified and communicated to decision makers For legacy systems, DMSMS tasking and data requirements included in applicable contracts Circuit design guidelines established Technology assessment and insertion under way DMSMS metrics established[a] Electronic data interchange used	All Level 3 practices implemented Technology road mapping used System upgrades planned Technology transparency attained Accessibility realized for alternate source development (VHDL, emulation, MEPs)

Notes: BOM = bill of materials, DMT = DMSMS management team, LRU = line replaceable unit, MEP = Manufacturing Extension Partnership, VHDL=VHSIC (Very High Speed Integrated Circuit) Hardware Description Language, WRA = weapons replaceable assembly.

[a]Metrics include number of cases, number of solutions implemented, life-cycle cost, and cost avoidance.

Table 5. DAU Training Course Tracks.[9]

Acquisition Management
Auditing
Business, Cost Estimating, and Financial Management
Contracting
Contracting Officer's Representative
Facilities Engineering
Grants
Industrial/Contract Property Management
Information Resource Management
Logistics
Production, Quality, and Manufacturing
Program Management
Requirements Management
Software Acquisition Management
Science and Technology Management
Systems Planning, Research, Development and Engineering
Test and Evaluation

serving a customer, organizations need to also be measuring their performance.

The successful implementation of a continuous improvement culture requires clearly defined roles and responsibilities in addition to a concise framework. The *CPIT Guidebook* identifies the roles and responsibilities of staff, members and the various DoD organizations needed to implement and execute CPI. In addition to providing roles and responsibilities, the *CPIT Guidebook* provides problem solving tools for eliminating waste and reducing variability in CPI efforts.[8]

The DoD *CPIT Guidebook* can be accessed electronically through the Defense Acquisition University's Publication website at http://www.dau.mil/pubscats/Lists/GuideBook/AllItems.aspx.

ONLINE RESOURCES

There are several online resources available for defense industry manufacturing engineers that can augment the compiled handbooks and guidebooks presented in the previous section. These resources include continuing education modules, technical forums, and Service-specific enterprise improvement websites.

Defense Acquisition University Resources

Training Courses

The Defense Acquisition University (DAU) provides continuous learning modules and training courses that cover a wide variety of technical, contractual, and management topic areas. Table 5 provides a complete list of DAU training course tracks. The tracks of greatest interest and highest importance to manufacturing engineers are the *Logistics* and *Production, Quality, and Manufacturing* (PQM) training course tracks. The Logistics Track offers courses on:

- Systems Sustainment Management,
- Reliability, Availability, and Maintainability (RAM),
- Intermediate Acquisition Logistics,
- Configuration Management,
- Intermediate Systems Sustainment Management,
- Performance-Based Logistics, and
- Enterprise Life Cycle Logistics Management.

More information on the Logistics Training Courses can be found at http://icatalog.dau.mil/onlinecatalog/tabnav.aspx?tab=LOG.

The PQM track offers courses on:

- Defense Specification Management,
- Specification Selection and Application,
- Intermediate Production, Quality, and Manufacturing,
- Preparation of Commercial Item Description for Engineering and Technical Personnel, and
- Advanced Production, Quality, and Manufacturing.[9]

For more information on the PQM Training courses, visit http://icatalog.dau.mil/onlinecatalog/tabnav.aspx?tab=PQM.

The Engineering and Technology continuous learning module provided by DAU contains several courses that are beneficial to manufacturing engineers in the defense industry as well. These courses cover modeling and simulation, ISO certifications, value engineering, Technology Readiness Assessments (TRAs), and process improvement methods such as Six Sigma and Lean Six

Figure 1. PQM Module Home Page.[10]

Table 6. PQM Topic Areas.

Hot Topics
Policy & Guidance
Product Design
Process Design & Control
Lessons Learned
Continuous Process Improvement
Supply Chain Management
e-Manufacturing
Tools
Training Center
Community Connection
Assessing Manufacturing Risk

Sigma. Detailed information on the continuous learning modules offered by the DAU can be found at http://icatalog.dau.mil/onlinecatalog/tabnavcl.aspx.

Acquisition Community Connection Production, Quality and Manufacturing (PQM) Portal

In addition to offering continuing education courses in manufacturing-related topic areas, DAU also houses an online portal where defense industry engineers, program managers, and other acquisition-related personnel can gather and share relevant information (reference material, best practices, websites, and case studies). The Production, Quality and Manufacturing (PQM) module houses several resources related to manufacturing within the defense industry. The PQM module has twelve topic areas, as presented in Table 6. Each topic area has a Question and Answer forum, a list of applicable metrics, and a brief overview of what is new to that topic area. The information contained in the PQM portal is provided by members of the PQM community and is updated regularly. Figure 1 shows a screenshot of the PQM module homepage.[10]

Continuous Process Improvement/Lean Six Sigma Program Office

A subordinate of the Office of the Deputy Chief Management Officer, the Continuous Process Improvement Lean Six Sigma Program Office (CPI/LSS) was established in 2007 to help the DoD components meet their CPI goals.[11] The CPI/LSS Office assists the individual Services in the initialization and sustainment of CPI efforts. In addition, the CPI/LSS Office collects process improvement best practices and provides training to develop performance improvement capabilities throughout the DoD. Further information on the CPI/LSS Office can be found at http://dcmo.defense.gov/index.html.

Army Continuous Process Improvement (CPI) Knowledge Center

The Continuous Process Improvement Knowledge Center (CPIKC) is a component of the Army Office of Business Transformation. This center provides the framework (Table 7) as well as the tools and techniques necessary to identify Army customers' needs and requirements (commonly known as the "Voice of the Customer") and for optimizing processes to meet the Army's needs.[7] The CPIKC also provides resources that raise awareness, provide insight into, and replicate best business practices. Tools and templates that support process improvement initiatives are provided.[7] In addition, the CPIKC provides critical success factors and industry best practices to improve the effectiveness of Army CPI efforts.

Table 7. Army CPI Framework Steps.

Step	Title
1	Define Business Drivers
2	Architect & Align Strategies
3	Develop Vision
4	Current State Understanding
5	Future State Design
6	Road Map Development
7	Execution
8	Continuing Improvement

The information, resources, and best practices available through the Army's Continuous Process Improvement Knowledge Center can be accessed at http://www.armyobt.army.mil/cpi-kc-welcome.html.

SUMMARY

The production of DoD weapon systems is extremely challenging, especially for manufacturing engineers, due to the elevated performance, quality, and lifespan standards required by the DoD. Ensuring that a weapon system is produced in the most efficient manner, while also meeting performance and quality specifications requires a focused approach for both development and production. This focused approach should be based upon the lessons learned and best practices obtained over several decades of weapon system production. The availability of this information along with program offices dedicated to the optimization of manufacturing processes are vital to manufacturing engineers responsible for producing weapon systems that meet performance and quality specifications. In the future, increased access to requirements, best practices, lessons learned, as well as increased collaboration between manufacturing colleagues (through forums and online portals) will help ensure that DoD weapon systems are produced at the highest quality for the right cost.

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Joint Defense Manufacturing Technology Panel

The Joint Defense Manufacturing Technology Panel (JDMTP) consists of technical principals from the individual Manufacturing Technology (ManTech) Programs of the Air Force, Army, Navy, Defense Logistics Agency (DLA), and Missile Defense Agency (MDA); the Office of the Secretary of Defense; the Department of Energy; and the Department of Commerce. This panel, chartered in 1999, has main objectives to guide the investment strategy for the Department of Defense (DoD) ManTech Program and to develop strategies that can be utilized by the ManTech Programs to mature and transition emerging manufacturing technologies to, and across, the Services. The JDMTP is also responsible for reporting to and executing tasks assigned by the Director of Defense Research and Engineering (DDR&E).[1]

Although focused on ManTech, the JDMTP's roles are multifaceted. Not only does the JDMTP provide investment and technology insertion guidance for DoD ManTech, but it also reviews and assesses DoD-related manufacturing problems and identifies areas for collaboration between the individual ManTech programs, private industry, and academia. This broadened teaming enables the JDMTP to increase the ManTech return on investment and transition to mature and novel manufacturing technologies in a reduced amount of time. The JDMTP is also responsible for developing methods by which information can be exchanged between subject matter experts in the manufacturing community to assist in the identification of manufacturing technology solutions. Similarly, because the JDMTP is a collaborative group, they can work to minimize instances of effort duplication within the ManTech Programs.[2]

Aside from assisting the ManTech Program physically, the JDMTP also assists the office of the Under Secretary of Defense for Advanced Systems and Concepts (DUSD(ASC)) in developing, when needed, and biennially updating the five-year DoD ManTech Strategic Plan.[3] This plan outlines the DoD ManTech Strategic Thrusts, overviews the defense manufacturing industry's current strategies, and describes the role of the DoD ManTech Program within those strategies. In parallel, the JDMTP is responsible for ensuring that current ManTech efforts are integrated and coordinated with those initiatives developed by other federal organizations and the Office of the Secretary of Defense (OSD).[1]

Strategies developed by the JDMTP are structured around one of its four technical subpanels (Figure 1). A brief description of each subpanel's focus is presented in Table 1. The individual ManTech programs also use these subpanels to optimize the use of available funding and to enable the development of relevant manufacturing processes.[4]

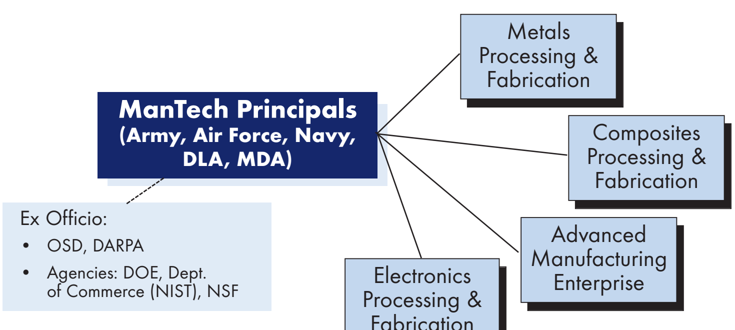

Figure 1. JDMTP Structure.[3,5]

Table 1. JDMTP Technical Subpanel Focuses.[2, 5]

Subpanel	Focus
Metals Processing and Fabrication	Address development of agile, cost-effective processes for state-of-the-art ferrous and non-ferrous alloys, specialty materials, material joining, and material inspection
Composites Processing and Fabrication	Address development of affordable, robust processes for fabrication of advanced composite structures for implementation in aircraft, ships, soldier protection, and ground vehicles
Electronics Processing and Fabrication	Address development of fabrication processes for integrated circuitry, printed circuit boards, electronic devices, analog and digital electronics, photonics, electro-optic devices
Advanced Manufacturing Enterprise	Accelerate implementation of world-class industrial practices, advanced design, and information systems that support weapon system development, production, and sustainment

In addition to the technical subpanels, the JDMTP also uses working groups to provide a more focused approach for solving issues that affect multiple services. For example, in 2001 the JDMTP created a joint working group that focused on identifying a method to assess manufacturing maturity and to provide a classification or measurement system for the various stages of process maturity, since a lack of manufacturing maturity was noted to be a recurring problem throughout the DoD. Comprised of representatives from the DoD Science & Technology, DoD Acquisition, industry, and academia, this working group developed the Manufacturing Readiness Level (MRL) definitions and the assessment process framework.

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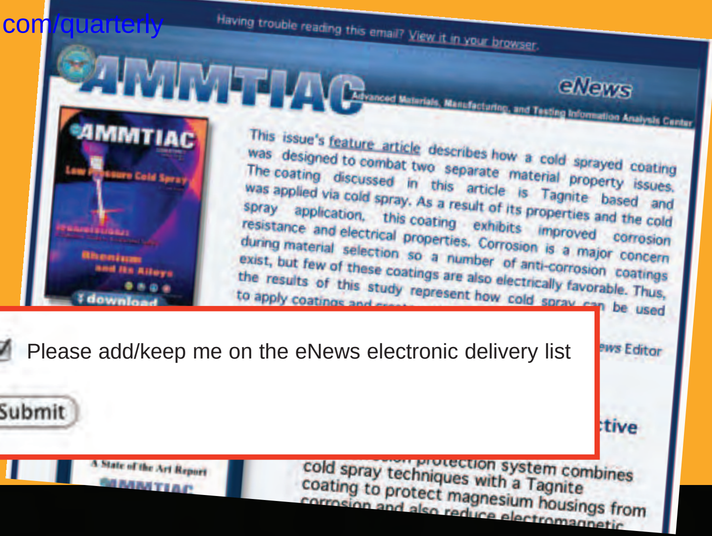

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