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Advanced Product Transitions Corp.

Streamlining Manufacturing Readiness Level Assessments

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Streamlining Manufacturing Readiness Level Assessments

Introduction

One of the Manufacturing Readiness Level Working Group (MRLWG) thrust areas currently open for discussion is the topic of "MRL Lites", also described as "Tailored MRLs." The *Early Manufacturing & Quality Engineering Guide*, Jul 2022, discusses use of a tailored assessment approach, "MRA Lite," in §3.3 and then refers in the appendix to the topic as "MRL Lite," as if they are synonymous terms. The term Manufacturing Readiness Assessment (MRA) is a generalized reference to assessments of manufacturing maturity and risks which have been, and continue to be, performed very successfully as part of systems engineering without using the MRL criteria and metrics. MRLs, as developed by the MRLWG and published in the MRL Deskbook, are just one approach to accomplishing an MRA, even if MRLs are the preferred approach by DoD.

The terms "Tailored MRL" and "MRL Lite" connote choosing which threads to apply or answer. The *Early M&Q Guide* approach suggests choosing certain threads and subthreads to include and combines maturity levels in the criteria. Choosing which threads to apply is an MRA, similar to but not equivalent to an assessment using the MRL process. The *M&Q Guide* approach introduces new levels, a new subthread sequence, and a combination of criteria; while leaving out MRL subthreads on cost, cybersecurity, and manufacturing management. The *Guide* in Table A-1 shows a sample with 16 subthreads and combined levels that on analysis are not consistent with the existing MRL criteria at the appropriate levels. Additionally, this "Lite" approach is only intended for early screening of system concepts and prototypes during early pre-Materiel Development Decision (MDD) candidate solution set development.[1] If this approach is used and referred to as an "MRA Lite," it could provide indications of manufacturing risks but it is not a reduced burden MRL assessment.

Our approach to "streamline" MRLs retains all 9 threads and MRL levels in sequence, but reduces the number of subthreads from 24 to 12. These streamlined criteria and metrics can be applied during pre-MDD evaluations, the Materiel Solutions Analysis (MSA) Phase for Major Capability Acquisition (MCA) systems, and/or throughout the acquisition life cycle for subsystems, items, and components. This streamlined approach to MRL assessments addresses the interest shown by the MRL community as a means of reducing the burden of performing MRL assessments, yet still identifies products or elements that are likely to have manufacturing risks.

In addition to streamlining, we also evaluated the filter questions from the *2022 MRL Deskbook*, §4.3, and added questions for Technology and Cybersecurity subthreads. We then made other clarifying changes to link the questions directly to the threads and streamlined subthreads.

Streamlining MRLs for MCA Programs at the System Level

We began with the MCA MRL Matrix with the intent to keep the 9 threads intact and in sequence. To do so, we examined the 24 subthreads individually to determine the most essential criterion and subthread

[1] *Early Manufacturing and Quality Engineering Guide*, Appendix A, Jul 2022.

within each thread. This led to eliminating some subthreads and combining others, while modifying some of the criteria.

For example, the cost subthreads were combined into one subthread with two criteria to determine if costs are analyzed and tracked, and in line with the funding. Supply chain criteria were combined into supplier management and supplier quality criteria as one subthread, asking the status of the supply chain and tracking the supplier quality. Also combined were subthreads I.2 Materials Planning and DE.2 Materials Availability, which are inherently connected; and E.2 Manufacturing Maturity and E.3 Yields concentrating materials management and maturity into just two subthreads.

Subthreads that were not retained for this streamlined assessment were focused on the technical aspects or details of manufacturing as development proceeds and are less likely to contribute to manufacturing risk. This included new technology for manufacturing (A.2), tooling and associated test equipment (H.1), product or process modeling (E.1), producibility trades for design (B.1), and special handling (hazardous materials, ESOH, etc.) (D.4). Additional subthreads not retained were focused on management aspects that often are already mature in organizations, such as quality management and manufacturing management.

This simplified and streamlined the criteria and subthreads to the 12 most essential subthreads. We restated some of the subthreads with a focus on the most important features. These include:

- A – Technology & Industrial Base
  - A.0 – Technology Maturity
  - A.1 – Industrial Base
- B – Design
  - B.2 – Design Maturity
- C – Cost & Funding
  - C.1 C.2 C.3 – Cost & Funding
- D -- Materials
  - D.1 – Materials Maturity
- E – Process Capability
  - E.2 – Manufacturing Maturity and (E.3) Yields
- F – Quality
  - F.2 – Product Quality
  - F.3 – Supplier Quality and (D.3) Supply Chain Management
- G – Manufacturing Workforce
  - G.1 – Manufacturing Workforce
- H -- Facilities
  - H.2 – Facilities
- I – Manufacturing Management
  - I.2 – Materials Planning and (D.2) Availability
  - I.3 – Manufacturing OT Cybersecurity

Although these subthreads span the full MRL 1 to 10 development maturity range and milestones used in MCA programs, this approach was not intended to be used beyond Milestone A at the system level, unless a special situation or significant resource constraints exist. Appendix A shows the streamlined criteria matrix as tied to the Milestone Decision points A, B, and C.

For MCA programs, filter questions should only be used at the subsystem, item, and component levels, not at the system level. Early in MCA development, either a streamlined MRL assessment or a full MRL

assessment must be performed. At Milestone B and later, a full MRL assessment must be performed at the system level, based on established policy and guidance.

During pre-MDD for the Concepts Design Review (CoDR), a streamlined MRL assessment should be performed on the system to MRL 3 in support of the MDD. During Analysis of Alternatives (AoA), a streamlined assessment to judge progress using MRL 4 could be performed. To conclude the MSA Phase and for the Alternative Systems Review (ASR), either a streamlined or a full MRL 4 assessment should be performed at the system level in support of the Milestone A decision. Beyond this point in the program, full MRL assessments are to be performed at the system level per the Systems Engineering Plan.

Streamlining MRLs for MCA Subsystems, Items, and Components

Below the system level at the subsystem, item, and component levels, the filter questions should be applied to prioritize which elements could be subject to a streamlined MRL assessment at a minimum. A full MRL assessment of these elements should be performed, if there is significant risk found either through application of the filter questions or the streamlined MRL assessment.

Streamlining Manufacturing Readiness Level Assessments

Filter questions

These filter questions are a combination of those in the *2022 MRL Deskbook* and in the *M&Q Guide* with the addition of the specific subthread annotation and changes to the question titles to match the subthread. To maintain clarity, the following questions are directly related to the threads and streamlined subthreads:

Technology Maturity (A.0): Is any of the technology to be used new or novel in the current application?

Industrial Base (A.1): Is the industrial base footprint capable of meeting the program's needs, or are there identified critical shortfalls or gaps in the industrial base?

Design Maturity (B.2): Does the item design contain nonstandard dimensions, geometries, or tolerances?

Cost & Funding (C.1, C.2, & C.3): Is this item a cost driver that has a significant impact on unit or life cycle cost (development, unit, or O&S costs)? Is the technology new with excessively uncertain cost?

Materials Maturity (D.2): Does the item include new and/or unique materials that have not been demonstrated in similar products or manufacturing processes?

Manufacturing Maturity (E.2): Will the item require use of manufacturing technology, processes, inspection, or capabilities that are unproven in the current environment?

Product Quality (F.2): Does the item have historical or anticipated yield or quality issues; or are there new quality requirements (i.e., inspection techniques, test equipment) that must be developed and proven?

Supplier Quality and Supply Chain Management (F.3 & D.3): Does the item have anticipated or historical subtier supplier problems (e.g., sole source, foreign source) that could negatively impact cost, quality, or delivery?

Manufacturing Workforce (G.1): Does the product require workforce skills and personnel that are not currently available?

Facilities (H.2): Does this item require a new manufacturing facility or major updates of existing facilities (e.g., new capability or capacity) to meet production and scale-up requirements?

Materials Planning & Availability (I.2 & D.2): Does this item present lead time issues, manufacturing concerns, or Diminishing Manufacturing Sources and Material Shortages (DMSMS) concerns on the critical path that could significantly impact the program schedule?

Manufacturing OT Cybersecurity (I.3): Are there anticipated cybersecurity weaknesses and vulnerabilities associated with manufacturing, supply chain or Operational Technology (OT) related to Critical Program Information in the Program Protection Plan (PPP) or that need to be addressed?

Subsystems, Items, and Components Matrix

After the risks in subsystems, items, and components have been identified such that "an MRL assessment may be needed," they should be prioritized by number of risk areas identified by the filter questions. Then a determination should be made as to how many can be assessed based on budget and schedule, using either the streamlined MRLs or a full MRL assessment. At the lower levels, even though there are normally no "Milestone Decisions," there are still similar decision points at the system level from following the Systems Engineering process (specified in IEEE 15288.2). Points such as: "Do you have a preliminary design?"; "Is the design complete?"; and "Are you ready for initial production?" To this end, we adapted the terminology of the system level streamlined MRLs for lower levels as follows:

- Materiel Development Decision (MDD) => Development Decision (DD)
- Milestone A => Decision Point 1 (D1)
- Milestone B => Decision Point 2 (D2)
- Critical Design Review transition => Decision Point 3 (D3)
- Milestone C (or LRIP Decision) => Decision Point 4 (D4)
- Full Rate Production Decision => Decision Point 5 (D5)

See Appendix B for the streamlined matrix with adaptation for Decision Points.

Mid-Tier Acquisition (MTA) Programs

The DoD Adaptive Acquisition Framework (AAF) MTA pathway is used to either accelerate capability maturation before transitioning to another acquisition pathway, or is used to minimally develop a capability. Whether using the rapid prototyping path or the rapid fielding path, streamlining may be used. Typically, Milestone Decisions (A, B, or C) are not applicable until transition to an MCA program. The above streamlined MRL assessment method for subsystems, items, and components with adaptation of the language, can be used. The streamlined criteria matrix is shown in Appendix B. The adaptation is that even though there are no "Milestone Decisions," there are still decision points that should be utilized until the MTA program transitions. Filter questions are not applicable at the MTA program level (system), either a streamlined or full MRL assessment should be used. Once a program transitions and is subject to MCA requirements, a full MRL assessment should be conducted.

Urgent Capability Acquisition (UCA) Programs

As UCA programs have operational urgency the normal acquisition processes are "aggressively streamlined" with a goal of achieving capability with development and production measured in months. A streamlined MRL assessment would be very beneficial to a UCA program, starting with the filter questions and, if necessary, conducting a streamlined MRL assessment. This will provide, at minimum, an understanding of the manufacturing risks involved in rapidly delivering capability.

Streamlining Manufacturing Readiness Level Assessments

Summary

The term “Manufacturing Readiness Assessment” is a generalized reference to assessments of manufacturing maturity and risk which have been, and continue to be, performed very successfully without using the MRL criteria and metrics as part of systems engineering. MRLs, as developed by the MRLWG, are one approach to accomplishing an MRA and are the preferred approach by DoD.

The terms “Tailored MRL” and “MRL Lite” imply choosing which threads to apply or answer and results in an MRA, similar to, but not equivalent to, an assessment using the MRL process. The *Early Manufacturing and Engineering Guide* shows a sample, which is not consistent with the existing MRL criteria at the appropriate levels. This “Lite” approach is limited by the *Guide* to early pre-MDD candidate solution set development. This approach is not a reduced burden or streamlined MRL assessment.

The approach presented here is to streamline MRLs by retaining all 9 threads and MRL levels in sequence, but reducing the number of subthreads to 12. These streamlined criteria and metrics can be applied during pre-MDD evaluations, in the MSA Phase for MCA systems, and/or throughout the acquisition life cycle for the lower tier subsystems, items, and components. This streamlined approach to MRL assessments addresses the interest shown by the MRL Working Group and community as a means of reducing the burden of performing MRL assessments, yet will still identify products or elements that are likely to have manufacturing risks. Applying streamlined MRL assessment approach at any level will increase the number of products or elements that can be assessed within budget and schedule with available resources.

Appendix A – Major Capability Acquisition Matrix

Acquisition Phase		Pre-Materiel Development Decision (Pre -MDD)			Materiel Solution Analysis (MSA)	Technology Maturation and Risk Reduction (TMRR)		Engineering & Manufacturing Development (EMD)		Low-Rate Initial Production (LRIP)	Full -Rate Production (FRP)
Technical Reviews				MDD	ASR A	SRR/SFR	PDR B	CDR	PRR/SVR C	PCA FRP	
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
A - Technology & Industrial Base	A.0 Technology Maturity	Technology concept and/or applications formulated	Component and/or breadboard validation in a laboratory environment.	Component and/or breadboard validation in a relevant environment.	Subsystem model or prototype demonstration in a relevant environment.	System model or prototype demonstration in a relevant environment.	System prototype demonstrated in an operational environment.	System prototype demonstrated in an operational environment.	Actual system completed and qualified through test and demonstration.	Actual system proven through successful mission operations.	Actual system proven through successful mission operations.
	A.1 Industrial Base	Trends in emerging industrial base capabilities identified	Potential industrial base capability gaps identified.	Industrial base capabilities for potential sources identified for system concepts.	Industrial base including capacities and capabilities surveyed for preferred materiel solution included in AoA.	Industrial base analysis to identify sources and minimize sole/single/FOCI initiated.	Industrial base capacity and capability analyses including avoidance or justification of sole/single/FOCI complete.	Industrial base capacity and capability analyses including sole/single/FOCI justification complete and monitored.	Industrial base capacity and capability analysis for MS C completed and capability is in place to support LRIP.	Industrial base capacity and capability analysis for FRP completed and capability in place to support FRP.	Industrial base analysis capacity and capability supports FRP.
B - Design	B.2 Design Maturity	Current capability deficiencies and gaps identified.	Analyses performed to evaluate the feasibility of potential solutions.	High level requirements defined and evaluated for system concepts.	Initial KPPS and manufacturing capabilities identified for preferred systems concept.	Product data required for prototype component manufacturing released and design KCs identification initiated.	Product data essential for subsystem/ system prototyping released and preliminary design KCs identified.	All product data essential for component manufacturing released and potential KC risks and issues identified.	All product data essential for system manufacturing released.	Major product design features and configuration are stable.	Product design is stable.
C - Cost & Funding	C.1 C.2 C.3 Cost & Funding	Initial manufacturing and quality costs identified and manufacturing investment strategy developed.	Potential manufacturing and quality cost drivers identified and program has funding to reach MRL 3.	Initial cost models and targets developed and program has funding to reach MRL 4 by MS A	Cost risks and issues assessed against targets for preffered materiel solutions and program has funding to reach MRL 6 by MS B.	Costs analyzed against targets using prototype component actuals and program has funding to reach MRL 6 by MS B.	Costs analyzed against targets using prototype system/sub-system actuals and program has funding to reach MRL 8 by MS C.	Manufacturing costs tracked against targets and program has funding to reach MRL 8 by MS C.	Costs analyzed against targets using pilot line actuals and program has funding to reach MRL 9 by FRP decision.	LRIP cost goals met and program has funding for FRP.	FRP cost goals met and program has funding to support program production at required rates and schedule.
D - Materials	D.1 Materials Maturity	New material properties and characteristics surveyed and identified for research (e.g., manufacturability, quality).	Potential effects of new material properties on design application manufacturability and quality predicted based on research.	Effects of new material properties on design concept manufacturability and quality validated using experiments and models.	New materials and components for preferred materiel solution demonstrated in a laboratory environment.	Materials manufactured or produced in a prototype environment (may be in a similar application/program).	Material maturity verified through technology demonstration articles.	Material maturity sufficient for pilot line build.	Materials proven and validated during EMD as adequate to support LRIP.	Materials proven and validated as adequate to support FRP.	Materials controlled to specifications in FRP.
E - Process Capability	E.2 Manufacturing Maturity	Concepts developed for relationships between process variables, stability, and repeatability including future yields and rates.	Concepts for processes identified and yields and rates tested through experimenting and prototyping.	Critical process control variables and initial yields and rates identified through pre acquisition experimenting and prototyping.	Maturity assessment of processes, yields, and rates for preferred materiel solution completed and considered in the AoA.	Process maturity assessment of similar processes used to establish target yields and rates for pilot line LRIP, and FRP.	Manufacturing processes including yields and rates demonstrated in production relevant environment.	Manufacturing processes including yields and rates demonstrated in a production representative environment.	Manufacturing processes including yields and rates refined and verified on pilot line for LRIP.	Manufacturing processes including yields and rates during LRIP are stable, adequately controlled, and capable for FRP.	Manufacturing processes including yields and rates are stable, adequately controlled, and capable.

Appendix A

Acquisition Phase		Pre-Materiel Development Decision (Pre -MDD)			Materiel Solution Analysis (MSA)	Technology Maturation and Risk Reduction (TMRR)		Engineering & Manufacturing Development (EMD)		Low-Rate Initial Production (LRIP)	Full -Rate Production (FRP)
Technical Reviews				MDD	ASR A	SRR/SFR	PDR B	CDR	PRR/SVR C	PCA FRP	
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
F - Quality	F.2 Product Quality	Quality metrology state of the art surveyed.	Elements identified which have a potential impact on quality.	Initial product quality requirements, risks, and issues identified. Inspection technologies identified.	Product quality requirements and the inspection and acceptance testing strategy documented.	Roles and responsibilities identified for acceptance test procedures, in-process and final inspections, and statistical process controls.	KC management approach defined with appropriate inspection and acceptance test procedures identified.	KC control plans developed including test and inspection.	KCs managed with test and inspection plans complete and validated.	KCs and other manufacturing processes critical to quality, are capable and under control for FRP.	KCs controlled in FRP.
	F.3 Supplier Quality and D.3 Supply Chain Management	Trends for supply chain quality, capability, and capacity surveyed.	Potential supply chain quality, capability, and capacity identified.	Supply chain requirements, capability, and capacity gap closure strategies defined.	Supply chain requirements, capability and capacity considered in the AoA.	Potential suppliers and supply chain quality capabilities and risks identified.	Lifecycle Supply Chain requirements updated and Supply chain quality improvements identified.	Supplier quality data from production representative units analyzed including assessment of critical first tier supply chain.	Supplier products qualification testing and first article inspection completed including assessment of critical second and lower tier supply chain.	Supplier management of manufacturing demonstrates capability and control and that the supply chain is stable and adequate to suppor FRP.	Supplier quality data shows adequate management of manufacturing and that the supply chain proven to supports FRP.
G - Manufacturing Workforce	G.1 Manufacturing Workforce	Workforce skill sets to support emerging trends in manufacturing and technology surveyed.	Workforce skill sets to support emerging trends in manufacturing and technology evaluated.	Workforce skill set requirements for system concepts identified.	Workforce skill set and workforce requirements identified.	Skill sets identified and plans developed.	Manufacturing workforce skills available for the production relevant environment.	Manufacturing workforce resource requirements identified and plans developed to achieve pilot line requirements.	Manufacturing workforce resource requirements identified and plans developed to achieve LRIP requirements.	Plan to achieve FRP workforce requirements implemented.	Production workforce skill sets maintained in spite of workforce attrition.
H - Facilities	H.2 Facilities	Current facility capabilities and capacity surveyed.	Potential facility capabilities and capacity requirements identified.	Facility capabilities and capacity requirements and gaps for system concepts identified.	Capability and availability of manufacturing facilities for prototype development of the preferred materiel solution evaluated.	Manufacturing facilities identified and plans developed to produce prototypes.	Manufacturing facilities identified and plans developed to produce pilot line build.	Manufacturing facilities identified and plans developed to produce LRIP build	Pilot line facilities demonstrated. Manufacturing facilities adequate to begin LRIP.	Manufacturing facilities in place and demonstrated in LRIP.	Production facilities in place and capacity demonstrated to meet maximum FRP requirements.
I - Manufacturing Management	I.2 Materials Planning and D.2 Availability	Trends for material availability, lead time, obsolescence, DMSMS, handling, and storage surveyed and identified for research.	Initial availability, lead time, obsolescence, DMSMS, handling, and storage requirements for potential materials and components evaluated.	Initial materials planning requirements including availability, lead times, obsolescence, DMSMS, handling, and storage identified.	Materials and components list with estimates for availability, lead times, handling and storage requirements including hazardous materials developed.	Make/buy evaluations including availability risks and issues initiated for pilot line, LRIP, and FRP.	BOM initiated with most make/buy decisions complete including availability risks and issues for EMD.	BOM and make/buy decision complete with availability risks and issues to meet LRIP mitigated.	BOM and make/buy decision complete with availability risks and issues to meet LRIP managed.	BOM and make/buy decision complete with availability risks and issues to meet FRP managed.	Material planning systems validated with material availability risks and issues managed in FRP.
	I.3 Manufacturing OT Cybersecurity	Trends in OT cybersecurity surveyed.	OT cybersecurity strategy and approach identified.	OT cybersecurity requirements for system concepts identified.	OT cybersecurity capabilities and cyber-vulnerabilities evaluated and risks identified including the potential supply chain.	OT cybersecurity requirements identified and development efforts initiated.	OT cybersecurity solutions demonstrated in a production relevant environment including supply chain.	OT cybersecurity solutions demonstrated in a production representative environment including supply chain.	OT cybersecurity incidents are identified and assessed including supply chain.	OT cybersecurity incidents are identified and mitigated including the supply chain.	OT cybersecurity procedures reviewed and updated.

Appendix B – Subsystems, Items, and Components Matrix

Acquisition Phase		Pre-Development Decision (Pre–DD)			Materiel Solution Analysis (MSA)	Technology Maturation and Risk Reduction (TMRR)		Engineering & Manufacturing Development (EMD)		Production Phase	
								Development	Demonstration	Low-Rate Initial Production (LRIP)	Full-Rate Production (FRP)
Technical Reviews				CoDR	DD ASR	D1 SRR/SFR	PDR	D2 CDR	D3 PRR/SVR	D4 PCA	D5
Thread	Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
A - Technology & Industrial Base	A.0 Technology Maturity	Technology concept and/or applications formulated	Component and/or breadboard validation in a laboratory environment.	Component and/or breadboard validation in a relevant environment.	Subsystem model or prototype demonstration in a relevant environment.	System model or prototype demonstration in a relevant environment.	System prototype demonstrated in an operational environment.	System prototype demonstrated in an operational environment.	Actual system completed and qualified through tes and demonstration.	Actual system proven through successful mission operations.	Actual system proven through successful mission operations.
	A.1 Industrial Base	Trends in emerging industrial base capabilities identified.	Potential industrial base capability gaps identified.	Industrial base capabilities for potential sources identified for system concepts.	Industrial base including capacities and capabilities surveyed for preferred materiel solution included in Analysis of Alternatives.	Industrial base analysis to identify sources and minimize sole/single/FOCI initiated.	Industrial base capacity and capability analyses for D2 including avoidance or justification of sole/single/FOCI complete.	Industrial base capacity and capability analyses for D3 including sole/single/FOCI justification complete and monitored.	Industrial base capacity and capability analysis for D4 completed and capability is in place to support LRIP.	Industrial base capacity and capability analysis for D5 completed and capability in place to support FRP.	Industrial base analysis capacity and capability supports FRP.
B - Design	B.2 Design Maturity	Current capability deficiencies and gaps identified.	Analyses performed to evaluate the feasibility of potential solutions.	High level requirements defined and evaluated for system concepts.	Initial KPPS and manufacturing capabilities identified for preferred systems concept.	Product data required for prototype component manufacturing released and design KCs identification initiated.	Product data essential for subsystem/ system prototyping released and preliminary design KCs identified.	All product data essential for component manufacturing released and potential KC risks and issues identified.	All product data essential for system manufacturing released.	Major product design features and configuration are stable.	Product design is stable.
C - Cost & Funding	C.1 C.2 C.3 Cost & Funding	Initial manufacturing and quality costs identified and manufacturing investment strategy developed.	Potential manufacturing and quality cost drivers identified and program has funding to reach MRL 3.	Initial cost models and targets developed and program has funding to reach MRL 4 by DD.	Cost risks and issues assessed against targets for preferred materiel solutions and program has funding to reach MRL 6 by D2.	Costs analyzed against targets using prototype component actuals and program has funding to reach MRL 6 by D2.	Costs analyzed against targets using prototype system/sub-system actuals and program has funding to reach MRL 8 by D3.	Manufacturing costs tracked against targets and program has funding to reach MRL 8 by D4.	Costs analyzed against targets using pilot line actuals and program has funding to reach MRL 9 by D5.	LRIP cost goals met and program has funding for FRP.	FRP cost goals met and program has funding to support program production at required rates and schedule.
D - Materials	D.1 Materials Maturity	New material properties and characteristics surveyed and identified for research (e.g., manufacturability, quality).	Potential effects of new material properties on design application manufacturability and quality predicted based on research.	Effects of new material properties on design concept manufacturability and quality validated using experiments and models.	New materials and components for preferred materiel solution demonstrated in a laboratory environment.	Materials manufactured or produced in a prototype environment (may be in a similar application/program).	Material maturity verified through technology demonstration articles.	Material maturity sufficient for pilot line build.	Materials proven and validated during EMD as adequate to support LRIP.	Materials proven and validated as adequate to support FRP.	Materials controlled to specifications in FRP.
E - Process Capability	E.2 Manufacturing Maturity	Concepts developed for relationships between process variables, stability, and repeatability including future yields and rates.	Concepts for processes identified and yields and rates tested through experimenting and prototyping.	Critical process control variables and initial yields and rates identified through pre acquisition experimenting and prototyping.	Maturity assessment of processes, yields, and rates for preferred materiel solution completed and considered in the Analysis of Alternatives.	Process maturity assessment of similar processes used to establish target yields and rates for pilot line, LRIP, and FRP.	Manufacturing processes including yields and rates demonstrated in production relevant environment.	Manufacturing processes including yields and rates demonstrated in a production representative environment.	Manufacturing processes including yields and rates refined and verified on pilot line for LRIP.	Manufacturing processes including yields and rates during LRIP are stable, adequately controlled, and capable for FRP.	Manufacturing processes including yields and rates are stable, adequately controlled, and capable.

Appendix B

Acquisition Phase		Pre-Development Decision (Pre–DD)			Materiel Solution Analysis (MSA)	Technology Maturation and Risk Reduction (TMRR)		Engineering & Manufacturing Development (EMD)		Production Phase	
								Development	Demonstration	Low-Rate Initial Production (LRIP)	Full-Rate Production (FRP)
Technical Reviews				CoDR	DD ASR	D1 SRR/SFR	PDR	D2 CDR	D3 PRR/SVR	D4 PCA	D5
Thread	**Sub-Thread**	**MRL 1**	**MRL 2**	**MRL 3**	**MRL 4**	**MRL 5**	**MRL 6**	**MRL 7**	**MRL 8**	**MRL 9**	**MRL 10**
F - Quality	F.2 Product Quality	Quality metrology state of the art surveyed.	Elements identified which have a potential impact on quality.	Initial product quality requirements, risks, and issues identified. Inspection technologies identified.	Product quality requirements and the inspection and acceptance testing strategy documented.	Roles and responsibilities identified for acceptance test procedures, in-process and final inspections, and statistical process controls.	KC management approach defined with appropriate inspection and acceptance test procedures identified.	KC control plans developed including test and inspection.	KCs managed with test and inspection plans complete and validated.	KCs and other manufacturing processes critical to quality, are capable and under control for FRP.	KCs controlled in FRP.
	E.3 Supplier Management and F.3 Quality	Trends for supply chain quality, capability, and capacity surveyed.	Potential supply chain quality, capability, and capacity identified.	Supply chain requirements, capability, and capacity gap closure strategies defined.	Supply chain requirements, capability, and capacity considered in the Analysis of Alternatives.	Potential suppliers and supply chain quality capabilities and risks identified.	Lifecycle Supply Chain requirements updated and Supply chain quality improvements identified.	Supplier quality data from production representative units analyzed including assessment of critical first tier supply chain.	Supplier products qualification testing and first article inspection completed including assessment of critical second and lower tier supply chain.	Supplier management of manufacturing demonstrates capability and control and that the supply chain is stable and adequate to support FRP.	Supplier quality data shows adequate management of manufacturing and that the supply chain proven to supports FRP.
G - Manufacturing Workforce	G.1 Manufacturing Workforce	Workforce skill sets to support emerging trends in manufacturing and technology surveyed.	Workforce skill sets to support emerging trends in manufacturing and technology evaluated.	Workforce skill set requirements for system concepts identified.	Workforce skill set and workforce requirements identified.	Skill sets identified and plans developed.	Manufacturing workforce skills available for the production relevant environment.	Manufacturing workforce resource requirements identified and plans developed to achieve pilot line requirements.	Manufacturing workforce resource requirements identified and plans developed to achieve LRIP requirements.	Plan to achieve FRP workforce requirements implemented.	Production workforce skill sets maintained in spite of workforce attrition.
H - Facilities	H.2 Facilities	Current facility capabilities and capacity surveyed.	Potential facility capabilities and capacity requirements identified.	Facility capabilities and capacity requirements and gaps for system concepts identified.	Capability and availability of manufacturing facilities for prototype development of the preferred materiel solution evaluated.	Manufacturing facilities identified and plans developed to produce prototypes.	Manufacturing facilities identified and plans developed to produce pilot line build.	Manufacturing facilities identified and plans developed to produce LRIP build	Pilot line facilities demonstrated. Manufacturing facilities adequate to begin LRIP.	Manufacturing facilities in place and demonstrated in LRIP	Production facilities in place and capacity demonstrated to meet maximum FRP requirements.
I - Manufacturing Management	I.2 Materials Planning and D.2 Availability	Trends for material availability, lead time, obsolescence, DMSMS, handling, and storage surveyed and identified for research.	Initial availability, lead time, obsolescence, DMSMS, handling, and storage requirements for potential materials and components evaluated.	Initial materials planning requirements including availability, lead times, obsolescence, DMSMS, handling, and storage identified.	Materials and components list with estimates for availability, lead times, handling and storage requirements including hazardous materials developed.	Make/buy evaluations including availability risks and issues initiated for pilot line, LRIP, and FRP.	BOM initiated with most make/buy decisions complete including availability risks and issues for EMD Phase.	BOM and make/buy decision complete with availability risks and issues to meet LRIP mitigated.	BOM and make/buy decision complete with availability risks and issues to meet LRIP managed.	BOM and make/buy decision complete with availability risks and issues to meet FRP managed.	Material planning systems validated with material availability risks and issues managed in FRP.
	I.3 Manufacturing OT Cybersecurity	Trends in OT cybersecurity surveyed.	OT cybersecurity strategy and approach identified.	OT cybersecurity requirements for system concepts identified.	OT cybersecurity capabilities and cyber-vulnerabilities evaluated and risks identified including the potential supply chain.	OT cybersecurity requirements identified and development efforts initiated.	OT cybersecurity solutions demonstrated in a production relevant environment including supply chain.	OT cybersecurity solutions demonstrated in a production representative environment including supply chain.	OT cybersecurity incidents are identified and assessed including supply chain.	OT cybersecurity incidents are identified and mitigated including the supply chain.	OT cybersecurity procedures reviewed and updated.