MRL 1-4 Criteria Development, S&T Workshop Results, and Recommended Path-Forward

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EXECUTIVE SUMMARY AND BACKGROUND

USD(R&E)/ODASD(SE) funded a project in late 2017 to have Design-Vantage Technologies, LLC to develop DRAFT MRL 1-3 that were presented to the MRL Working Group at their January 2018 meeting. A key distinction between the approach used by Design-Vantage Technologies, LLC and previous attempts to develop MRL 1-3 criteria was recognizing that there are two primary customers the MRL must serve in the pre-MDD acquisition process: 1) the early systems engineering (SE) development planning community and 2) the early science and technology (S&T) community. The resulting criteria were thus designed to enable manufacturing and quality (M&Q) considerations to be integrated into the early SE development of Joint Operations Concepts (JOCs), Capability Based Assessments (CBAs), and Initial Capability Documents (ICDs). These three JCIDS processes are focused on developing and evolving the maturity of operational requirements for system development efforts that fully define the problem to be solved pre-MDD that precede the development of technical requirements that fully describe the types of solutions that are needed post-MDD going into the analysis of alternatives (AoA). In addition, the DRAFT MRL 1-3 criteria also build the M&Q knowledge base required to support the development of more robust Technology Transition Agreements (TTAs) between the acquisition and S&T communities. The result is that the maturity of the M&Q operational requirements associated with the DRAFT MRL 1-3 criteria for each of the sub-threads now treats industrial base development with the same SE-based rigor used to develop warfighter operational requirements.

This document summarizes the overall approach and rationale used to develop the DRAFT MRL 1-3 criteria enhancements to the MRL 4 criteria that were presented at the January 2018 MRL WG meeting aimed at driving the maturity of M&Q operational requirements pre-MDD and improved M&Q technical requirements going into the AoA post-MDD. It also summarizes the results of a July 2018 MRL 1-3 workshop with the S&T community, additional enhancements to the overall MRL 1-4 approach and rationale that resulted from the workshop, and recommendations for a path forward. Also included is an analysis of the Department of Homeland Security (DHS) TRL 1-4 exit criteria requirements which significantly expand upon the historical DOD and NASA TRL evaluation approaches which largely rely on the use of the TRL descriptions rather tan objective exit criteria. This analysis includes both an affinity-based mapping of the DHS TRL 1-4 exit criteria into TRL threads or themes that the exit criteria are aimed at driving, which were then mapped to the MRL threads to demonstrate how the DRAFT MRL 1-4 criteria help support and provide information that directly feed into and support the DHS TRL 1-4 exit criteria requirements. It is believed that the DRAFT MRL 1-4 criteria support the new administration's Undersecretary of Defense for Research and Engineering (USD(RE)) imperative to accelerate the development of manufacturing S&T (MS&T) efforts as well as the transition of advanced manufacturing technologies into the warfighter and the industrial base.

MRL 1-4 CRITERIA DEVELOPMENT APPROACH

Previous attempts at developing MRL 1-3 criteria have focused on trying to extrapolate the criteria further left in the product development and acquisition process have been largely unsuccessful because the thread "names" start to lose relevance to the early S&T and early community. The approach used to develop the DRAFT MRL 1-4 criteria described in this document took a different approach and started all the way left in the early product developmental planning and acquisition process and worked right by developing MRL 1, MRL 2, and MRL 3 criteria that aligned with activities and the knowledge base being generated by the early systems engineering (SE) and early S&T (6.1 basic and 6.2 applied research) communities. The existing MRL 4 criteria were then analyzed to see if the MRL 1-3 criteria converged to the same end state, with enhancements to the MRL 4 criteria for the threads also drafted based on the richer knowledge base the MRL 1-3 criteria drove that now become inputs to the product development trade study and acquisition Analysis of Alternative (AoA) processes that mark the beginning of product development.

In early product developmental planning (pre-MDD in the acquisition cycle), there are two parallel maturation paths, one for early systems engineering and one for early S&T, that generate both a knowledge that feed into concept refinement and technology development pathways as depicted in Figure 1. And once a decision to develop a new product is made, TRL and MRL assessments are used as part of the pre-launch trade study process (AoA in the acquisition cycle) to balance risk with the ability to meet customer requirements for system concept refinement and technology development (6.3 research) that must converge by the time a decision is made to launch the program and begin engineering and manufacturing development activities (MS B in the acquisition cycle) as shown in the figure. Also shown in Figure 1 are the three distinct TRL/MRL maturation regimes that the MRL criteria need to align with: 1) building the early manufacturing SE and S&T knowledge base for TRL/MRL 1-3 activities; 2) driving integration of manufacturing considerations into and convergence of system concept refinement and technology development for TRL/MRL 4-6; and 3) driving manufacturing considerations throughout the product development process for TRL 7-9 and MRL 7-10 activities.

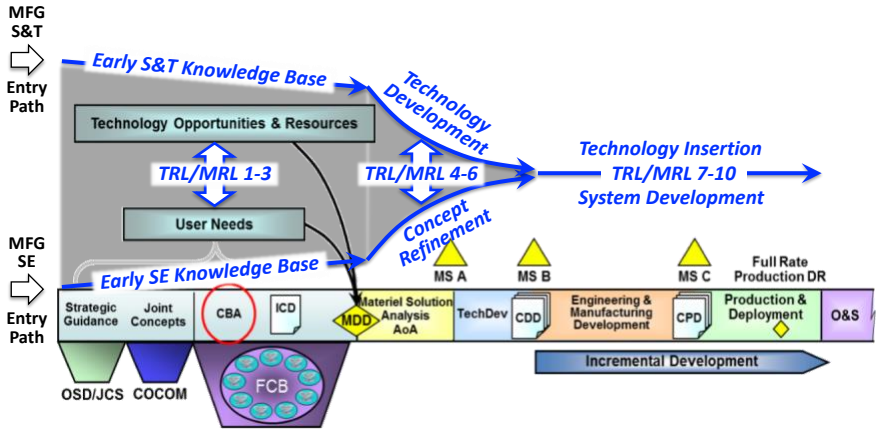

Figure 1: MRL Continuum and the Convergence of Parallel SE and S&T Pathways

An alternative way to graphically show the three distinct MRL maturation regimes is to map the existing MRL 4-10 criteria to the DOD SE V-model as shown in Figure 2. Note that in the DOD

SE V-model taken from the systems engineering chapter of the Defense Acquisition Guidebook (DAG) there are also three distinct regimes that SE processes focus on: 1) at the top of the V-model SE processes focus on early pre-MDD development planning which focus on understanding mission need capability gaps and developing operational requirements and candidate solution set system concepts; 2) the middle of the V-model focuses on traditional SE processes that decompose the operational requirements into technical requirements and system specifications that define the needed solutions; and the bottom of the V-model focuses on SE processes for hardware, software, and specialty engineering that design the actual product. As shown in Figure 2, when the MRL criteria are mapped to the SE V-model the MRL 1-3 criteria need to support early development planning activities, the MRL 4-7 criteria need to support the decomposition of operational requirements into design solutions, and the MRL 8-10 criteria need to support the realization of products that are validated solutions to providing the needed capabilities.

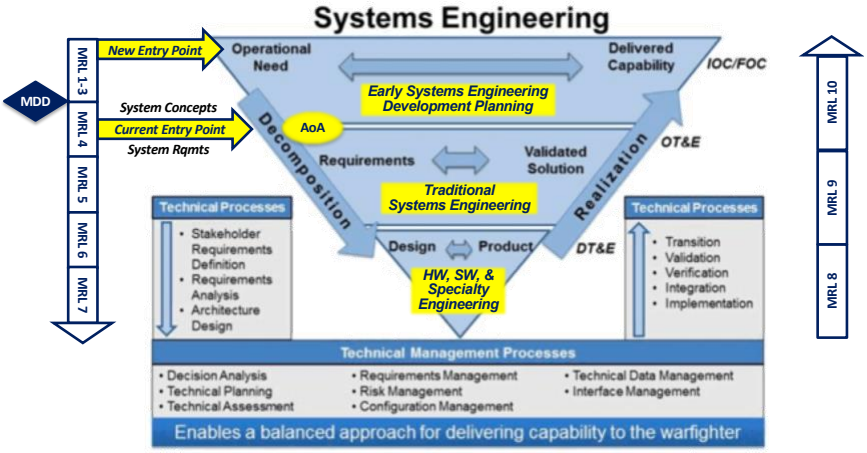

Figure 2: Mapping of MRL Criteria to the SE V-Model Processes

An analysis was performed on the existing MRL 7-10 criteria to validate the criteria aligned with this mapping, with the current entry point of the MRL criteria shown to support the integration of manufacturing considerations into system concepts and requirements that feed into the AoA trade study process. This MRL mapping also highlights the importance of the need for developing MRL 1-3 criteria needed to integrate manufacturing considerations into early SE developmental planning activities. Figure 3 taken from the USAF Early Systems Engineering Guidebook, illustrates the types of activities the types of early SE activities that the DRAFT MRL 1-3 criteria were developed to support in addition to early S&T activities described later. Thus, the MRL 1 criteria were developed to align with joint concepts development activities which focus on looking at evolving manufacturing threats, vulnerabilities, and capability gaps 3-5 years in the future and establishing current state baselines. The MRL 2 criteria were developed to align with capability-based assessment activities that analyze manufacturing capability gaps and identify the general types of solutions needed to address them. And the MRL 3 criteria were developed to align with initial capability document development activities that focus on characterizing manufacturing capability gaps and develop recommendations for specific solutions to address them.

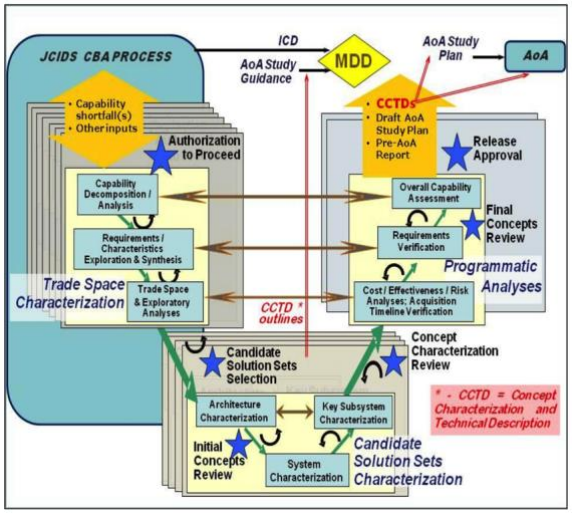

Figure 3: Early SE Activities the MRL 1-3 Criteria Need to Support

A similar thought process was used to develop MRL 1-3 criteria verbiage that align with the types of S&T TRL 1-3 activities that focus on creating a Manufacturing Science and Technology (MS&T) knowledge base as depicted in the LHS of Figure 4. Namely MRL 1 criteria for threads that support the creation of a MS&T first principles knowledge base were developed to align with supporting descriptive studies aimed at developing cause-effect hypothesis to understand the manufacturing implications the technology could have. The MRL 2 criteria were developed to align with supporting analytic studies aimed at testing the cause-effect hypotheses to help quantify the relative manufacturing implications the technology will have as practical MS&T applications are being invented and evaluated. And the MRL 3 criteria were developed to support the development of analytical models using analytic and experimental techniques to predict the manufacturing implications of the technology as the basic elements of the technology are integrated together and the MS&T efforts are transitioned into TRL/MRL 4-6 technology development activities. Also shown in Figure 4 is the alignment of the rationale used to develop that DRAFT MRL 1-3 criteria in a manner that supports both early S&T and early SE activities.

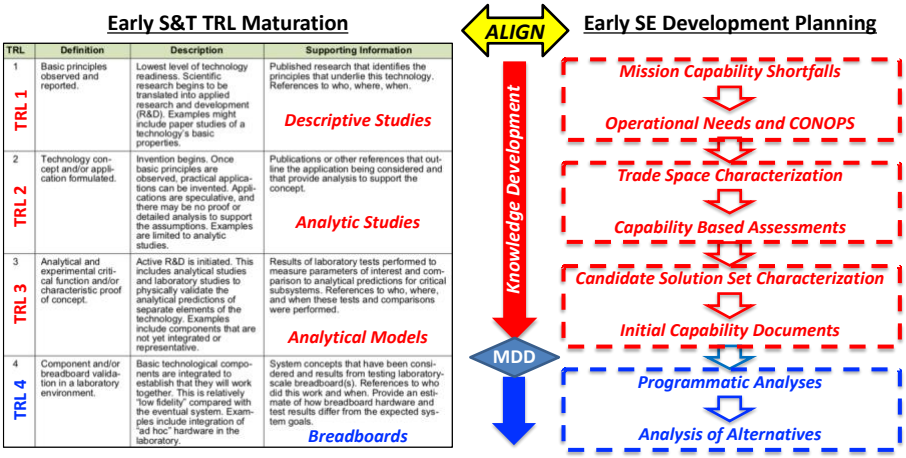

Figure 4: Alignment of MRL 1-3 Criteria with Early S&T and Early SE Activities

Finally, the last piece of the approach used to develop the DRAFT MRL 1-3 criteria was to develop an approach that addresses the fact that many of the thread and sub-thread "names" start to lose relevance and create a "perception" that the MRL criteria do not add value during early S&T and early SE activities because much of the information they are asking for is not available. The approach used was to analyze the existing MRL 4-10 criteria and affinity map them to the types of knowledge development activities that could be performed in early SE and early S&T MRL 1-3 activities based on the "outcome" the threads and sub-threads are aimed at driving going into the AoA trade study process. The result of this affinity mapping is shown in Figure 5 in which the sub-threads tended to cluster around three general functional areas: 1) knowledge associated with better supporting early manufacturing developmental planning and execution activities both strategic and tactical; 2) knowledge associated with better supporting assessing and evaluating manufacturing needs during trade space exploration; and 3) knowledge associated with better supporting activities focused on better analyzing and understanding manufacturing first principles; with Appendix A containing the detailed sub-thread affinity mapping results.

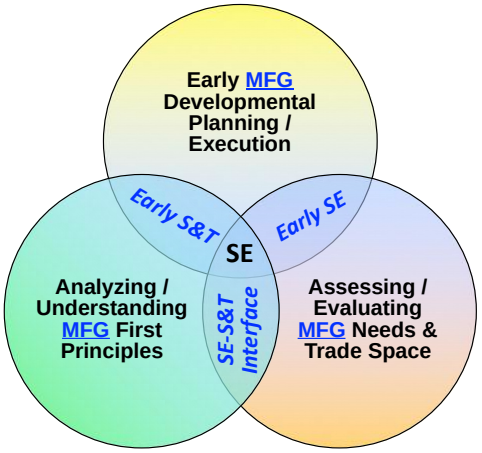

Figure 5: Affinity Mapping of MRL Sub-Thread Activities to Knowledge Outcomes

Following the January 2018 MRL Working Group meeting in which the DRAFT MRL 1-4 criteria v3.1 were presented, a dual product-production system V-model was developed to drive a focus on the fact that two systems are being developed in parallel in modern day system development efforts: 1) the product system and 2) the production system used to bring it into being which is shown in Figure 6. Using this model an additional MRL sub-thread affinity mapping was performed that revealed the outcomes of the sub-threads could also be viewed from the context of 1) being associated with activities associated with the design and development of the product system, 2) being associated with activities associated with the design and development of the production system, or 3) being associated with activities associated with the optimization, matching, coupling, and integration of these two systems (i.e., the system of systems view). The detailed results of the MRL sub-thread to system affinity mapping is included in Appendix B.

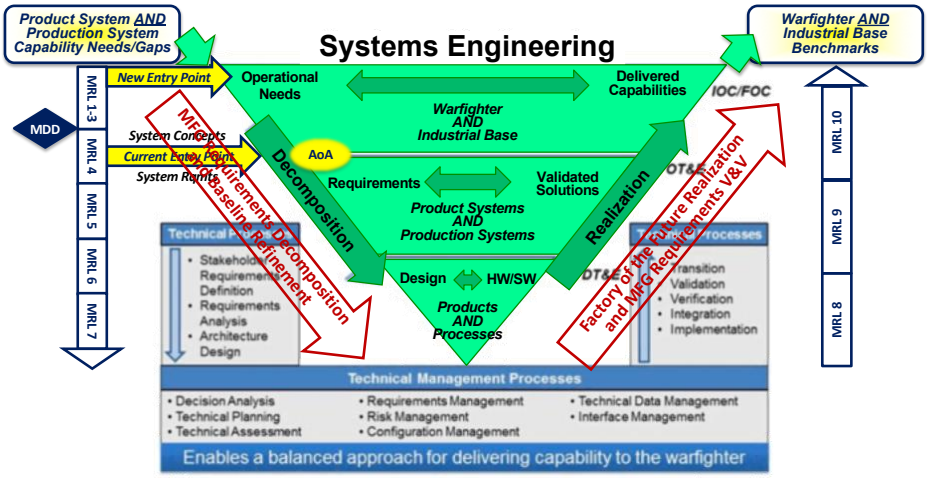

Figure 6: Dual Product-Production System V-Model

The dual product-production system V-model concept was then used develop the dual system TRL/MRL maturation regime model shown in Figure 7 that depicts how the MRL framework and the dual product-production system V-model could be utilized to better integrate manufacturing into and synchronize early SE and early S&T activities. Using this conceptual framework, the DRAFT MRL 1-4 criteria v3.1presented at the January 2018 MRL Working Group meeting were further refined to place a focus on creating the TRL/MRL 1-3 regime knowledge base not only from the context of the functional activities the sub-threads are aligned with but also the system of interest they then help support the design and development of as the AoA trade studies are conducted beginning with at TRL/MRL 4. The refined DRAFT MRL 1-4 criteria v4.2 are included in Appendix C and served as the baseline for an MRL 1-3 S&T Workshop that was help in July 2018 to capture input and feedback from the S&T community the output of which is described in a subsequent section that also forms the basis for this white paper's go-forward recommendations.

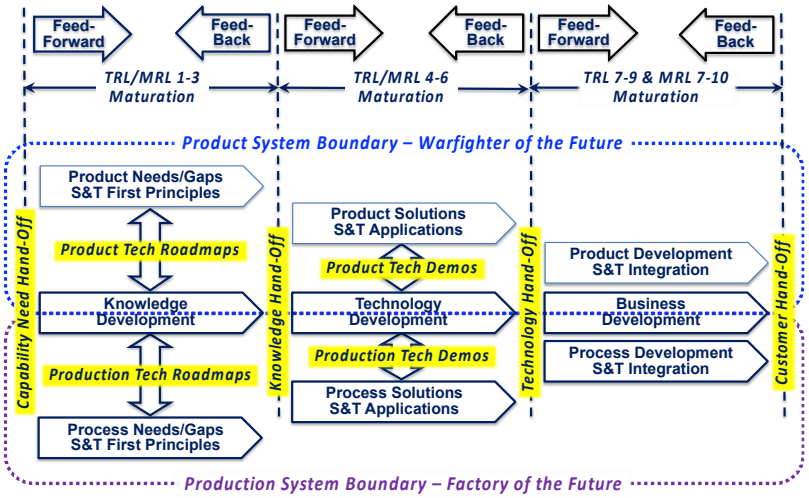

Figure 7: Dual System TRL/MRL Maturation Regime Model

In addition, as this white paper was being compiled the authors came across the Department of Homeland Security (DHS) Program Management Model for TRL Assessments included in Appendix D which contains a comprehensive set of considerations, exit criteria, and key deliverables. The DHS TRL Assessment Model is much more comprehensive than the criteria used by the DOD and NASA and is a huge leap forward in resembling the MRL matrix criteria as well as including a TRL Application to a Product Realization Roadmap Model that contains and on ramp that enters at TRL 1, exit ramps and on ramps at the TRL 3-4 transition hand-off, exit ramps and on ramps at the TRL 6-7 transition hand-off, and an exit ramp at TRL 9 at the bottom of the infographic contained in Appendix D that is similar to the TRL/MRL maturation regime model that was developed herein depicted in Figure 7. Thus, a detailed analysis of the DHS TRL 1-4 exit criteria was performed with affinity mapping performed to synthesize thread groupings or themes based on the outcomes the exit criteria drive and mapped to the MRL matrix sub-threads that is depicted in Figure 8, with the detailed affinity mapping results included in Appendix E.

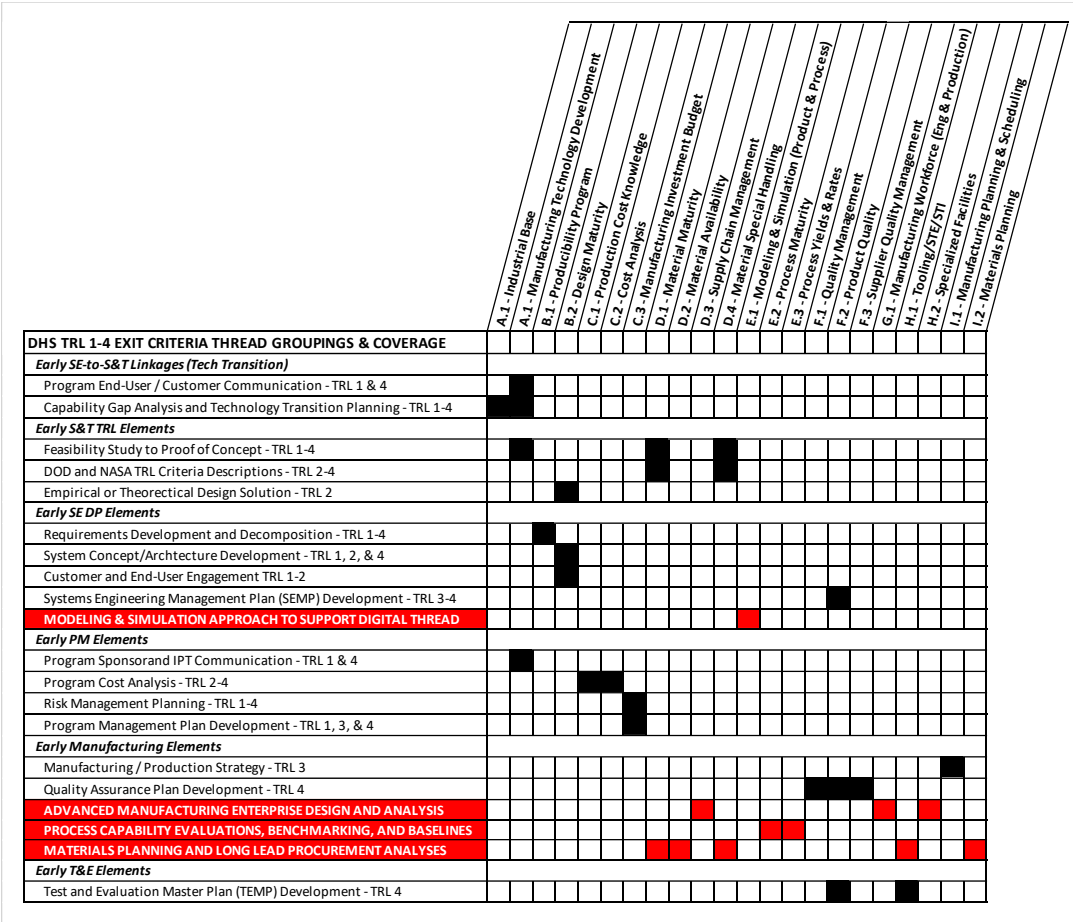

Figure 8: DHS TRL 1-4 Exit Criteria Thread Mapping to MRL Sub-Thread Criteria

As can be seen in Figure 8 as well as the more detailed affinity mapping in Appendix E, the DHS affinity grouped threads and associated sub-threads focus on driving early and proactive technology transition planning as well as early S&T, SE, program management (PM), manufacturing, and test and evaluation (T&E) considerations into a holistic technology maturation

plan. Also note that the areas highlighted in red in Figure 8 are associated with key manufacturing knowledge base development areas the MRL sub-threads capture that are not incorporated into the current DHS TRL 1-4 exit criteria. This analysis and conclusion that further validates the technical approach and rationale used to develop the DRAFT MRL 1-4 criteria and associated models presented in this white paper as well as the value these criteria provide to the early S&T and early SE communities if "properly integrated into TRL assessments". One of the recommendations of this white paper is to further explore the DHS TRL Assessment process and initiate discussions with that community for input on further refining and piloting the proposed DRAFT MRL 1-4 criteria as DHS has appeared to have leapfrogged ahead of other agencies in TRL leadership.

JULY MRL 1-3 S&T WORKSHOP OUTPUTS & RECOMMENDATIONS

Following the presentation of the DRAFT MRL 1-4 criteria v3.1 and the rationale used to develop them it was decided to hold an MRL 1-3 workshop with S&T community to capture their MRL needs, concerns, and feedback on both the DRAFT MRL 1-3 criteria and the rationale used to develop them. Just under 20 individuals attended the workshop either in person or participated virtually and included representatives from the MRL Working Group, ODASD(SE), ARL, ONR, AFRL, NSF. Boeing, Mississippi State University Institute for Systems Engineering Research, and the University of New Hampshire John Olson Advanced Manufacturing Center. Overall the feedback from the workshop participants was very positive and they liked the rigorous rationale and technical approach and had the following general feedback and suggestions which are planning to be incorporated into the DRAFT MRL 1-4 criteria v4.2 prior to the Annual MRL Workshop being help in September 2018.

- The DRAFT MRL 1-4 criteria in the matrix are not very user friendly and should be rewritten in terms that the average MRL assessment user can understand and relate to. The action for the author of this white paper is to re-draft the verbiage in the criteria and develop appropriate MRL Deskbook verbiage for any terms that are new to the MRL Working Group, namely name of the early systems engineering elements.
- It would be helpful to have descriptions of specific types of a knowledge base that each of the sub-threads build for both 1) the early S&T community and 2) the early SE community to better put what the criteria are asking in a proper context. A very preliminary DRAFT of Early S&T/SE sub-thread context descriptions was developed post-workshop and is included in Appendix F which needs to be further fleshed out by the white paper author.
- The right people were not in the room to evaluate the DRAFT MRL 1-4 criteria for the sub-threads associated with the main materials and processes thread categories, and the attendees suggested to gather their input and feedback before making any decision on further refining the criteria. It is recommended to hold a focus group and/or sponsor a mini-workshop to gather their input and feedback on the criteria and incorporate that into the matrix prior to releasing it for further review and feedback.
- One S&T attendee thought the MRL was moving too far left into the TRL 1-2 basic research regime and felt the criteria were not helpful for a large number of 6.1 S&T programs. Post-workshop this feedback was addressed by reviewing 6.1 research descriptions available on the AFOSR, ARL, and ONR websites to validate this feedback. The analysis found that ~20% of the 6.1 S&T portfolios for each organization had R&D thrusts that were material, process, or MS&T focused and these were very much aligned with the knowledge base the

MRL 1-3 criteria are aimed at building for engineering focused portfolio elements. Thus, it is recommended that 6.1 trigger criteria be developed to help identify what sub-sets of the 6.1 S&T portfolios can benefit from early MRL assessments and incorporate these into policy and guidance recommendations for engineering focused portfolio elements.

- About halfway through the workshop one of the attendees asked if specific post-mortem examples could be given for how the DRAFT MRL 1-4 criteria could have helped identify problems encountered during TRL/MRL 4-6 technology development activities due to an insufficient early MRL 1-3 knowledge base and what could have been done differently. Two examples were given by two of the attendees: 1) the development of a new alloy for a gas turbine engine impeller that was thought to be at TRL/MRL 6, but when it was transitioned into a program the lack of knowledge about its producibility characteristics were not well understood which resulted in extremely high levels of scrap and rework due to machinability issues that was not planned for that current generation cutting tool technologies were not capable of addressing; and 2) a hydrogen storage 6.1 basic research project that had a high potential for technology transition but encountered material availability and scalability issues associated with procuring the platinum catalyst needed to activate the carbon in the hydrogen storage unit. Both of these examples resulted in highly interactive discussions among the group and they felt more of these types of case studies need to be documented to demonstrate why early MRL 1-3 assessments are important and how the proposed DRAFT MRL 1-4 criteria could help drive different outcomes. The white paper author concurs with this recommendation.
- As the workshop discussions unfolded it started to become apparent to the author of the DRAFT VMRL 1-4 v4.2 criteria that in the TRL/MRL 1-3 regime the criteria should not be viewed as an orderly progression from TRL/MRL 1 to TRL/MRL 2 to TRL/MRL 3 like the TRL/MRL 4-10 criteria are used as a planning tool. Rather the MRL 1-3 criteria provide a continuum of three fundamental maturation steps necessary to incrementally and iteratively build the early SE and early S&T knowledge base going into the AoA trade study process at TRL/MRL 4, and that the rigor in use of the MRL 1-3 criteria will likely follow an S-curve shape that peaks at the AoA trade study entry point or the TRL/MRL 3-4 transition or hand-off. Viewing the MRL 1-3 criteria from a technology hand-off perspective at critical triggering events is very different from current TRL/MRL 4-10 technology and product development practices and requires a different way of thinking about where, when, and why early TRL/MRL 1-3 assessments are needed that fall outside of current policy and guidance defining when TRL and MRL assessments should first be performed. The three triggers for performing a TRL/MRL assessment as defined in current policy and guidance are at MS-A and MS-B per acquisition policy and guidance, during the MSA phase per DOD SE policy and guidance, and when a Technology Transition Agreement (TTA) is being drafted between the S&T and acquisition communities. It is recommended that further analysis be performed to identify additional triggering events based on technology hand-offs that could benefit from early TRL/MRL assessments and the relevant policy and guidance be developed to drive the needed early S&T and early SE manufacturing engagement culture change. Some additional triggering events for performing such early TRL/MRL assessments could be: 6.1-to-6.2 basic to applied research graduation (TRL 2-3 hand-off); 6.2-to-6.3 applied research to technology development graduation (TRL 3-4 hand-off) which also could be applied to Manufacturing USA applied R&D efforts.

- The final recommendation is to hold a similar MRL 1-3 SE workshop with the early SE development planning communities to capture their input and feedback on if the DRAFT MRL 1-4 v4.2 criteria and the rationale used to develop them help support initiatives they are working to improve SE processes. It is worth noting that the early SE development planning community was invited to but was not represented at the MRL 1-3 workshop due to schedule conflicts and it is felt their input and feedback is both necessary and value added before making the decision as to how to move forward with the proposed DRAFT MRL 1-3 v4.2 criteria either via a second MRL 1-3 workshop or focus groups.

SUMMARY AND RECOMMENDED PATH FORWARD

A rigorous SE-based approach was used to develop the proposed DRAFT MRL 1-4 criteria that aligns with early SE (operational requirements development) and early S&T (TRL 1-3 maturation vehicle alignment) pre-MDD objectives and builds the knowledge base required to integrate M&Q considerations into the early acquisition process. The overall approach, rationale used to develop the criteria, and the actual matrix criteria have been socialized with the S&T community and their feedback integrated into the recommendations documented herein. The same needs to be done with the early SE development planning community via a focus group and/or workshop as they are a key customer of the MRL 1-3 criteria and are the ones responsible for developing and evolving operational requirements through JOCs, CBAs, and ICDs pre-MDD as well as providing much of the information that feeds into TTAs between the acquisition and S&T communities. It should be noted that current acquisition and SE policy and guidance are what drive TRL/MRL evaluations, with no S&T requirements or policy and guidance specifying a need for TRL/MRL evaluations.

Trigger criteria thus need to be developed that define when early SE and early S&T MRL 1-3 assessments should be performed and by whom as the operational requirements maturity continuum does not follow a gate driven process to successively drive from one maturity level to the next as is currently done with the MRL 4-10 criteria. For 6.1 and 6.2 basic and applied research trigger criteria also need to be developed to help identify when and where an MRL assessment adds value, e.g., engineering vs. physics vs. general science focused research. In addition, these trigger criteria should also include subsequent knowledge hand-offs between the 6.1, 6.2, 6.3, and acquisition communities as these hand-offs are where "knowledge escapes" occur similar to product quality escapes. Once these triggering events/criteria are identified, it is suggested that OSD policy and guidance be drafted to drive the needed culture change with the MRL Deskbook also updated the provide a body of knowledge to implement the policy and guidance.

Case studies for how early MRL 1-3 evaluations could have helped identify and drove different decisions in latter stage TRL/MRL 4-6 technology development efforts need to be solicited and incorporated into the MRL Deskbook to illustrate the value the MRL 1-3 criteria provide. These case studies should encompass the entire spectrum of the 6.1, 6.2, and 6.3 spectrum and demonstrate the impact that inadequate planning/executing, analyzing/understanding, and assessing/evaluating MRL 1-3 activities have on MS&T focused project outcomes and technology transition plans. Once these case studies have been solicited and validated the MRL 1-3 criteria should be re-evaluated and refinements made to ensure that they build the relevant knowledge base that could have driven different MS&T outcomes and/or decisions.

Finally, it is believed that the proposed DRAFT MRL 1-4 criteria help support the new administration's imperative to accelerate the pace of MS&T development and the transition of these technologies into the warfighter and industrial base. As described in this document all of the feedback captured to date from the January 2018 MRL WG meeting and the July MRL 1-3 S&T Workshop has been captured and used to develop suggestion to enhance the proposed DRAFT MRL 1-4 criteria but not lose the essence of what type of M&Q knowledge is needed to better support pre-MDD activities. The current v4.2 version of the DRAFT MRL 1-4 criteria, however, still need to be revised with guidelines developed to ensure key early SE development planning is not stripped away for the sake of making the criteria easier to apply to early S&T efforts. The white paper author feels that early SE, early S&T, and early M&Q all need to have a seat at the table pre-MDD with the MRL 1-3 criteria conversation starters, with early SE and early S&T each owning different sub-threads and providing the information they are asking for.

APPENDIX A
DETAILED SUB-THREAD FUNCTIONAL AFFINITY MAPPING RESULTS

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DETAILED SUB-THREAD FUNCTIONAL AFFINITY MAPPING RESULTS

MRL 1-3 Knowledge Supports Planning/Executing Activities

Sub-Thread	MRL 4-10 Thread Artifact Outcome	Thread Activity Focus	MRL 1-3 Criteria Focus
A.2: Manufacturing Technology Development	Manufacturing Technology Development & Transition Plan	Planning/Executing (Strategic)	Product and Production System Manufacturing Capability Gaps and Technology Development Needs
C.3: Manufacturing Investment Budget	Manufacturing Budget Program Management	Planning/Executing (Strategic)	Manufacturing Technology Development Stakeholder Investment Priorities
D.2: Material Availability	Critical Material Procurement & Obsolescence Management	Planning/Executing (Strategic)	Current and Future State Critical Material, Obsolescence, & DMSMS Concerns and Risk Areas
I.1: Manufacturing Planning & Scheduling	Manufacturing Strategy/Plan Development	Planning/Executing (Strategic)	Manufacturing Competitiveness Strategy for Materiel and Non-Materiel Solutions
I.2: Materials Planning	Make/Buy Decisions & BOM Development	Planning/Executing (Strategic/Tactical)	WBS-Based Technology and Candidate System Solution Set Development Needs
D.4: Special Handling	Special Handling Procedure Development	Planning/Executing (Tactical)	Technology Raw Material and Component Special Handling Considerations
F.2: Product Quality	Inspection & Acceptance Test Methods/Criteria	Planning/Executing (Tactical)	Technology Verification and Validation (V&V) Methods/Criteria
H.1: Tooling, Special Test and Inspection Equipment (STE/SIE)	Special Tooling, Test, & Inspection Equipment	Planning/Executing (Tactical)	Technology Tooling/STE/SIE Considerations for Prototype Specimens, Devices, Components

MRL 1-3 Knowledge Supports Assessing/Evaluating Activities

Sub-Thread	MRL 4-10 Thread Artifact Outcome	Thread Activity Focus	MRL 1-3 Criteria Focus
A.1: Industrial Base	Industrial Base Capability Assessments	Assessing/Evaluating	Current and Emerging Industrial Base Capabilities and Core Competencies (Global Landscape not Supply Chain)
B.2: Design Maturity	Product Specification Development	Assessing/Evaluating	Product-Technology Insertion Measure of Effectiveness (MOE) Linkages (Precursor to Product System KPPs)
C.2: Cost Analysis	Design to Cost Methodology & Cost Feasibility	Assessing/Evaluating	System Affordability and Life Cycle Cost Drivers and Leverage Points
D.3: Supply Chain Management	Manufacturing "Buy" Strategy	Assessing/Evaluating	Current State Supply Chain Capability and Capacity Baselines and Future State Development Needs (Buy Production System Elements)
E.1: Modeling & Simulation (Product & Process)	Model-Based Product & Process Optimization	Assessing/Evaluating	Current State Manufacturing Model Based Systems Engineering Capability Baselines and Future State Development Needs
E.3: Process Yields and Rates	Manufacturing Yield & Throughput Management	Assessing/Evaluating	Current State Capacity Utilization & Yield Baselines and Future State Improvement Needs
F.1: Quality Management	Quality Management System Development	Assessing/Evaluating	Current State Quality Management System Baselines and Future State Development Needs (Make Production System Elements)
F.3: Supplier Quality Management	Sub-Tier Supplier Flow Down Specifications	Assessing/Evaluating	Current State Supplier Quality Management Baselines and Future State Improvement Needs (Buy Production System Elements)
G.1: Manufacturing Workforce (Engineering & Production)	K-Gray Workforce Development & Training	Assessing/Evaluating	Current State Workforce Skill Set Gaps and Future State Development Needs (Includes STEM Pipeline)
H.2 : Facilities	Manufacturing "Make" Strategy	Assessing/Evaluating	Current State Specialized Manufacturing Facility Baselines and Future State Development Needs (Make Production System Elements)

MRL 1-3 Knowledge Supports Analyzing/Understanding Activities

Sub-Thread	MRL 4-10 Thread Artifact Outcome	Thread Activity Focus	MRL 1-3 Criteria Focus
B.1: Producibility Program	Producibility & Manufacturability Optimization	Analyzing/Understanding (Assessing/Evaluating)	Technology-Producibility-Manufacturability Relationships (Same Rigor and Fidelity as Reliability-Availability-Maintainability)
C.1: Production Cost Knowledge (Cost modeling)	Cost Model Development & Refinement	Analyzing/Understanding (Assessing/Evaluating)	Technology Cost-Benefit Analyses and Technology Transition Value Proposition
D.1: Material Maturity	Material Specification Development	Analyzing/Understanding (Assessing/Evaluating)	Material Processing-Structure-Property Relationships for Critical Raw Materials and Components
E.2: Manufacturing Process Maturity	Manufacturing Process Capability Management	Analyzing/Understanding (Assessing/Evaluating)	Critical Manufacturing Process Stability and Repeatability Relationships and Control Variables

APPENDIX B
DETAILED SUB-THREAD SYSTEM AFFINITY MAPPING RESULTS

Product System — LHS of SE V-Model (Decomposition) — RHS of SE V-Model (Realization)

Sub-Thread	Thread System Focus	MRL 4-7 Criteria Focus	MRL 8-10 Criteria Focus
B.2: Design Maturity	Product System	System and Item Spec Development & Baseline Refinement (Product System Decomposition - LHS of SE V-Model)	System and Item Spec Verification & KC Control (Product System Realization - RHS of SE V-Model)
C.2: Cost Analysis	Product System	System Cost Analysis & Item Cost Target Allocation (Product System Decomposition - LHS of SE V-Model)	System Cost Verification & Cost Rediuction Goals (Product System Realization - RHS of SE V-Model)
D.1: Material Maturity	Product System	Material Characterization & Spec Development (Product System Decomposition - LHS of SE V-Model)	Material Specification Verification & Validation (Product System Realization - RHS of SE V-Model)
D.2: Material Availability	Product System	Material Availability & Long Lead Procurement Planning (Product System Decomposition - LHS of SE V-Model)	Material Availability & Long Lead Procurement SCM (Product System Realzation - RHS of SE V-Model)
D.4: Special Handling	Product System	Material Special Handling Spec & Procedure Development (Product-Production System Interface - LHS of SE V-Model)	Material Special Handling Deomonstration & Verification (Product-Production System Interface - RHS of SE V-Model)
F.2: Product Quality	Product System	Product Acceptance Test Procedure & Control Plan Development (Product System Decomposition - LHS of SE V-Model)	Product Quality Demonstration & KC Control (Product System Realization - RHS of SE V-Model)
H.1: Tooling, Special Test and Inspection Equipment (STE/SIE)	Product System	Production Tooling/STE/STI Spec Development (Product-Production System Interface - LHS of SE V-Model)	Production Tooling/STE/STI Demonstration & Verification (Product-Production System Interface - RHS of SE V-Model)

Production System — LHS of SE V-Model (Decomposition) — RHS of SE V-Model (Realization)

Sub-Thread	Thread System Focus	MRL 4-7 Criteria Focus	MRL 8-10 Criteria Focus
A.1: Industrial Base	Production System	Defense Industrial Base Analysis & Development (Production System Decomposition - LHS of SE V-Model)	Defense Industrial Base Capability Integration & Verification (Production System Realization - RHS of SE V-Model)
D.3: Supply Chain Management	Production System	Supply Chain Design & Requirements Development (Production System Decomposition - LHS of SE V-Model)	Supply Chain Requirements Flow Down & Management (Production System Realization - RHS of SE V-Model)
E.2: Manufacturing Process Maturity	Production System	Process Capability Characterixation & Spec Development (Production System Decomposition - LHS of SE V-Model)	Process Capability Verification & Continuous Improvement (Production System Realization - RHS of SE V-Model)
E.3: Process Yields and Rates	Production System	Production Yield and Rate Targets & Improvement Plans (Production System Decomposition - LHS of SE V-Model)	Production Yield & Rate Verification & Improvements (Production System Realization - RHS of SE V-Model)
F.1: Quality Management	Production System	Quality Target & Quality Management System Development (Production System Decomposition - LHS of SE V-Mode)	Quality Target Verification & Continuous Improvement (Production System Realization - RHS of SE V-Model)
F.3: Supplier Quality Management	Production System	Supplier Quality Management Flow Down Spec Development (Production System Decomposition - LHS of SE V-Model)	Supplier Quality Management Verification & Quality Audits (Production System Realization - RHS of SE V-Model)
G.1: Manufacturing Workforce (Engineering & Production)	Production System	Manufacturing Skill Set & Training Requirements Development (Production System Decomposition - LHS of SE V-Model)	Manufacturing Skill Set Requirements Verification & Training Plans (Production System Realization - RHS of SE V-Model)
H.2 : Facilities	Production System	Manufacturing Production Facility Development Planning (Production System Decomposition - LHS of SE V-Model)	Manufacturing Production Facility Demonstration & Verification (Production System Realization - RHS of SE V-Model)
I.1: Manufacturing Planning & Scheduling	Production System	Production Strategy & Manufacturing Plan Development (Production System Decomposition - LHS of SE V-Model)	Production Control System Implementation & Refinement (Production System Realization - RHS of SE V-Model)

System of Systems — LHS of SE V-Model (Optimization & Matching) — RHS of SE V-Model (Coupling & Integration)

Sub-Thread	Thread System Focus	MRL 4-7 Criteria Focus	MRL 8-10 Criteria Focus
A.2: Manufacturing Technology Development	Product-Production System Interactions	Manufacturing Technology Development & Implementation (Product System / Production System Optimization & Matching)	Manufacturing Technology Development & Implementation (Product System / Production System Coupling & Integration)
B.1: Producibility Program	Product-Production System Interactions	Producibility Evaluation & Enhancement (Product System / Production System Optimization & Matching)	Producibility Demonstration & Verification (Product System / Production System Coupling & Integration)
C.1: Production Cost Knowledge (Cost modeling)	Product-Production System Interactions	Cost Model Development & Refinement (Product System / Production System Optimization & Matching)	Cost Model Demonstration, Refinement, & Verification (Product System / Production System Coupling & Integration)
C.3: Manufacturing Investment Budget	Product-Production System Interactions	Manufacturing Maturation Investment Budget Management (Product System / Production System Optimization & Matching)	Manufacturing Maturation Investment Budget Management (Product System / Production System Coupling & Integration)
E.1: Modeling & Simulation (Product & Process)	Product-Production System Interactions	System and Item Modeling & Simulation Development (Product System / Production System Optimization & Matching)	System and Item Model & Simulation Verification (Product System / Production System Coupling & Integration)
I.2: Materials Planning	Product-Production System Interactions	Make/Buy Evaluations & BOM Development (Product System / Production System Optimization & Matching)	Material Planning System Verification & Validation (Product System / Production System Coupling & Integration)

APPENDIX C
DRAFT MRL 1-4 CRITERIA (V4.2)

Sub-Thread	MRL 1	MRL 2	MRL 3	MRL 4
A.1: Industrial Base	Current state global industrial base capabilities in key manufacturing functional areas identified along with global trends in emerging manufacturing capabilities. Future state industrial base manufacturing landscape shift scenarios in key manufacturing functional areas developed and incorporated into the manufacturing CONOPS analysis.	Industrial base manufacturing capability, competency, and competitiveness gaps in key manufacturing functional areas identified and prioritized in terms of operational risk. Future state industrial base footprint strategy defined and linked to the industrial base landscape shift scenarios associated with the manufacturing CONOPS analysis.	Industrial base manufacturing capability, competency, and competitiveness benchmarks for potential sources within the footprint assessed and characterized. Future state industrial base operational requirements defined that include measures of effectiveness (MOE's) with minimum and desired levels established that quantify when the desired industrial base sources have been sufficiently developed.	Industrial base capabilities of preferred sources within the footprint surveyed and known gaps/risks identified for preferred concept, key technologies, components, and/or key processes and used to develop industrial base technical requirements. Plans to develop preferred sources and address known gaps/risks established that are linked to the industrial base development MOE's.
A.2: Manufacturing Technology Development	Current state manufacturing capability shortcomings and advanced manufacturing technology capabilities identified that describe how the industrial base will perform enduring manufacturing functions 3-5 years in the future. Global manufacturing trends in emerging advanced manufacturing technologies identified and used to shape a high-level initial manufacturing technology development strategy to address current state industrial base capability shortcomings.	Manufacturing capability gaps identified and prioritized with recommendations provided to pursue types of advanced manufacturing solutions to address the gaps and provide the needed future state capabilities. Draft manufacturing technology roadmap developed that provides a preliminary manufacturing technology development strategy to mature the various types of solutions being recommended.	Manufacturing capability gaps characterized with specific solution approaches to address gaps identified and assessed to define key assumptions, limitations, and boundary conditions associated with the evaluations Manufacturing technology roadmap updated to document and define specific solution approaches to address the prioritized manufacturing capability gaps.	Initial determination of potential advanced manufacturing critical technology elements (CTE's) associated with roadmap gap closure solution approaches. Manufacturing Science & Advanced Manufacturing Technology requirements associated with each advanced manufacturing CTE identified, validated and incorporated into the advanced manufacturing technology roadmap.
B.1: Producibility Program	Descriptive studies performed to generate hypotheses about qualitative cause-effect relationships between critical technology variables and design dependent producibilty and manufacturability parameters. Design applications limited to material and/or process families/classes associated with the implementation of the technology.	Analytic studies performed to test and validate hypotheses about cause-effect relationships and establish quantitative correlations between critical technology variables and design dependent producibility and manufacturability parameters. Design applications limited to generic device families associated with the implementation of the technology, with potential part families for technology insertion identified which may be speculative.	Analytical and laboratory studies performed to develop and validate predictive models to quantify cause-effect relationships between critical technology variables and design dependent producibility and manufacturability parameters. Design applications identified that consist of distinctive part families associated with demonstrating practical applications of the technology.	Initial producibility and manufacturability assessment of preferred systems concepts completed and results incorporated into AoA trade studies. Results considered in selection of preferred design concepts and reflected in Acquisition Strategy key components/ technologies.
B.2: Design Maturity	Potential design applications identified that are limited to material and/or process families/classes associated with the implementation of the technology to address known system capability shortcomings. Manufacturing considerations incorporated into the system CONOPS need and gap analysis being considered in pre-MDD early development planning activities.	Potential design applications identified that are limited to generic device families associated with the implementation of the technology to address prioritized capability gaps, with potential part family applications for technology insertion identified which may be speculative. Potential design and manufacturing solution types identified that address prioritized operational capability gaps being considered in pre-MDD early development planning activities.	Potential design applications identified that consist of distinctive part families associated with demonstrating practical applications of the technology to address system and manufacturing CONOPS capability gaps. Product operational requirements developed that include measures of effectiveness (MOE's) to evaluate potential design and manufacturing solution approaches being considered in pre-MDD early development planning activities.	Potential design applications identified that are linked to distinctive product families associated with the system concepts and technical requirements being considered in the AoA trade studies. SEP and Test and Evaluation Strategy recognize the need for the establishment/validation of manufacturing capability and management of manufacturing risk for the product lifecycle. Initial potential Key Performance Parameters (KPPs) identified for preferred systems concept. System characteristics and measures to support required capabilities identified. Form, fit, and function constraints identified and manufacturing capabilities identified for preferred systems concepts.
C.1: Production Cost Knowledge (Cost modeling)	Descriptive studies performed to generate hypotheses about qualitative cost-benefit estimates associated with how the technology impacts system-level affordability. Value propositions formulated in terms of relative benefits associated with applications of the technology that are limited to material and/or process families/classes.	Analytic studies performed to validate rough order of magnitude (ROM) cost-benefit estimates associated with implementing the technology into practical applications. Value propositions formulated in terms of generic device application families associated with implementation of the technology, with potential part families identified for technology transition as part of the value proposition which may be speculative.	Analytical models developed and validated to predict and quantify ROM cost-benefit estimates associated with implementing the technology into distinctive types of part families associated with production hardware. Value propositions formulated in terms of potential technology transition opportunities that identify specific product families that utilize the types of part families upon which the cost-benefit analyses are based.	Potential product classes/lines identified that are associated with the types of technology insertion applications upon which the cost-benefit analyses are based. Cost-benefit estimates refined based on the actual production volumes associated with the system concepts considered in the AoA. Manufacturing, material and special requirement cost drivers identified. Detailed process chart cost models driven by process variables. Cost driver uncertainty quantified.
C.2: Cost Analysis	Current state system affordability shortcomings associated with the baseline system CONOPS identified. Future state system affordability improvement areas identified and incorporated into the system CONOPS need and gap analysis being considered in pre-MDD early development planning activities.	System affordability gaps identified and prioritized in terms of life cycle cost (LCC) impact. Potential system affordability solution type recommendations developed that address prioritized LCC reduction areas being considered in pre-MDD early development planning activities.	System affordability gaps characterized with specific affordability solution recommendations provided along with key LCC impact assumptions, limitations, and boundary conditions. System affordability requirements/constraints developed and incorporated into the system measures of effectiveness (MOE's) to enable the integration and evaluation of LCC reduction opportunities into pre-MDD early development planning activities.	System affordability and producibility cost risks assessed during system trade studies. Initial cost models support Analysis of Alternatives (AoA) and Alternative Systems Review (ASR). Initial potential Key Performance Parameters (KPP's) associated with LCC cost reduction activities for the preferred system concept and incorporated into the SEP and/or manufacturing maturation plan (MMP).
C.3: Manufacturing Investment Budget	Manufacturing technology portfolio investment strategy developed from a multi-agency and/or multi-stakeholder perspective that leverages investment synergies to develop cross-cutting advanced manufacturing capabilities 3-5 years in the future that address current state industrial base manufacturing capability shortcomings.	Recommendations to pool resources and develop joint investment strategies to address cross-cutting advanced manufacturing technology solutions developed. Manufacturing technology roadmap updated top reflect multi-agency and/or multi-stakeholder investment priorities.	Annual operating plans developed that define advanced manufacturing technology investments required to support current year roadmap gap closure priorities with multi-agency and/or multi-stakeholder cost-benefit analyses documented that provide rationale for needed investments. Specific technology transition targets identified and validated for joint investment concepts.	Manufacturing technology initiatives identified to reduce costs. Program has reasonable budget estimate for reaching MRL 6 by MS B. Estimate includes capital investment for production-relevant equipment. All outstanding MRL 4 risk areas understood with approved mitigation plans in place.

D.1: Material Maturity	Descriptive studies performed to generate hypotheses about qualitative processing-structure-property relationships for new material and component technology development efforts.	Analytic studies performed to test and validate hypotheses about processing-structure-property relationships and establish quantitative correlations that describe these relationships for new material and component technology development efforts.	Analytical and laboratory studies performed to develop and validate predictive models to quantify processing-structure-property relationships for new material and component technologies.	Projected materials and components have been produced in a laboratory environment with processing-structure-property relationships demonstrated to be controllable and repeatable.
D.2: Material Availability	Current state critical material, obsolescence, and DMSMS issues and risks identified along with forecasts for projected trends. Proactive approaches looking 3-5 years in the future defined that identify areas where manufacturing technology development efforts can be leveraged to address evolving gaps and risks.	Critical material, obsolescence, and DMSMS issues identified and prioritized in terms of operational risk. Manufacturing technology roadmaps updated to incorporate critical material, obsolescence, and DMSMS stakeholder needs into multi-agency investment strategies.	Alternative materials and manufacturing technology solutions to address material availability gaps identified and characterized. Key assumptions, limitations, and boundary conditions associated with potential solution approaches documented and used to develop risk mitigation plans.	Projected lead times have been identified for all difficult to obtain, difficult to process, or hazardous materials. Quantities and lead times estimated with material availability risks incorporated into AoA trade studies and risk mitigation plans incorporated into SEP for the preferred system concept.
D.3: Supply Chain Management	Current state supplier capability and capacity shortcomings for buy production system element supply chain sources on the Approved Supplier List (ASL) identified. Future state supplier capability and capacity development needs in key manufacturing functional areas established and incorporated into the manufacturing CONOPS.	Supply chain capability and capacity gaps associated with the current ASL and desired supply chain footprint identified and prioritized in terms of manufacturing CONOPS operational risk. Recommendations for broad types of alternative supply chain sources and supplier development solutions developed to address prioritized supply chain capability and capacity gaps for buy production system elements associated with the future state industrial base footprint strategy.	Supply chain capability and capacity gaps characterized for potential supply chain sources on the ASL that support the manufacturing CONOPS with recommendations for specific solutions to address the gaps provided along with supplier development assumptions, limitations, and boundary conditions. Industrial base operational requirements updated to incorporate source selection and supplier development requirements for buy production system elements associated with the desired industrial base footprint.	Survey completed for potential supply chain sources to determine their capability and capacity to support the manufacturing CONOPS and incorporated into the AoA. Source selection technical requirements developed and used to down-select preferred sources for buy production system elements associated with the preferred system concept. Supplier development technical requirements established to address documented supply chain capability gaps and incorporated into the manufacturing maturation plan (MMP).
D.4: Special Handling	Raw material and component special handling needs/requirements identified for material and/or process family/class specimen testing required to support hypothesis development to establish qualitative cause-effect relationships between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Raw material and component special handling needs/requirements identified for device family hardware testing required to support hypothesis validation to establish quantitative correlations between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Raw material and component special handling needs/requirements identified for part family component testing required to support analytical model development and validation for the quantitative prediction of cause-effect relationships between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	List of hazardous materials associated with the system concept refinement and/or technology development updated. Special handling procedures applied in the lab for prototype hardware fabrication. Special handling requirements identified for preferred system concepts and incorporated into the Systems Engineering Plan (SEP).
E.1: Modeling & Simulation (Product & Process)	Current state manufacturing modeling/simulation capability shortcomings identified based on the ability to support manufacturing model based systems engineering (MBSE) activities. Future state manufacturing MBSE capability development needs identified and used to shape a high-level manufacturing MBSE development strategy to address current state manufacturing modeling/simulation capability shortcomings.	Manufacturing modeling/simulation capability gaps identified and prioritized with recommendations provided to pursue types of MBSE solutions to address the gaps and provide the needed future state capabilities. Draft manufacturing modeling/simulation roadmap developed that provides a preliminary manufacturing MBSE development strategy to mature the various types of solutions being recommended.	Manufacturing modeling/simulation capability gaps characterized with specific MBSE solution approaches to address gaps identified and assessed to define key assumptions, limitations, and boundary conditions associated with the evaluations Manufacturing MBSE roadmap updated to document and define specific solution approaches to address the prioritized manufacturing modeling/simulation capability gaps.	Production system manufacturing modeling/simulation approaches for process or product are identified and incorporated into the system and manufacturing concept MBSE strategy.
E.2: Manufacturing Process Maturity	Descriptive studies performed to generate hypotheses about qualitative cause-effect relationships between critical process control variables and process stability and repeatability for critical manufacturing processes.	Analytic studies performed to test and validate hypotheses about cause-effect relationships and establish quantitative correlations between critical process control variables and process stability and repeatability for critical manufacturing processes.	Analytic and laboratory studies performed to develop and validate predictive models that quantify cause-effect relationships between critical process control variables and process stability and repeatability for critical manufacturing processes.	Complete a survey to determine the current state of critical processes for preferred system concepts and supply chain sources. Process capability technical requirements and improvement plans developed and incorporated into the SEP for critical processes and supply chain sources.
E.3: Process Yields and Rates	Current state manufacturing yield estimate baselines and capacity utilization rates defined for critical manufacturing processes and supply chain sources of critical materials and components in the ASL. Future state manufacturing yield and capacity utilization rate improvement areas for critical processes and suppliers identified and incorporated into the manufacturing CONOPS and supplier development plans.	Manufacturing yield and capacity utilization rate improvement targets for critical manufacturing processes and suppliers defined and prioritized based on operational risk to the manufacturing CONOPS. Broad types of solutions defined that provide a path forward to achieve the yield and capacity utilization rate targets in the manufacturing CONOPS for all critical manufacturing processes and suppliers identified in the ASL.	Manufacturing yield and capacity utilization rate gaps characterized for critical processes and suppliers with specific solutions to address gaps and mitigate the operational risk of achieving the targets identified and evaluated. Industrial base operational requirements for yield and capacity utilization rate improvements developed with industrial base measures of effectiveness updated to include yield and capacity utilization rate considerations for critical processes and supply chain sources.	Yield and rates assessment on proposed/similar processes complete for the alternative systems and manufacturing concepts and technical requirements for improvements developed and applied within Analysis of Alternatives (AoA). Manufacturing yield and capacity utilization rate improvement targets validated for the preferred system and manufacturing concept and incorporated in the manufacturing maturation plan (MMP).

F.1: Quality Management	Current state quality management system capability shortcomings identified along with trends in emerging quality management system technological capabilities (e.g., information technology solutions, metrology solutions, data analytics solutions). Future state quality management system improvement areas associated with non-materiel solution investments identified and incorporated into the manufacturing competitiveness strategy.	Quality management system capability gaps prioritized in terms of manufacturing CONOPS operational risk. Recommendations for broad types of alternative quality management system technological non-materiel solutions developed to address prioritized quality management system gaps and incorporated into the manufacturing competitiveness strategy.	Quality management system capability gaps characterized with recommendations for specific quality management system technological non-materiel solutions to address the gaps provided and incorporated into the manufacturing competitiveness strategy.	Quality strategy identified for the preferred system concept as part of the Acquisition Strategy and included in Systems Engineering Plan (SEP). Quality management system improvement plans updated to incorporate technological non-materiel solutions to address known capability gaps.
F.2: Product Quality	Validation and verification methods/criteria defined for material and/or process family/class specimen testing required to support hypothesis development to establish qualitative cause-effect relationships between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Validation and verification methods/criteria defined for device family hardware testing required to support hypothesis validation to establish quantitative correlations between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Validation and verification methods/criteria defined or part family component testing required to support analytical model development and validation for the quantitative prediction of cause-effect relationships between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Product inspection and acceptance testing strategy for preferred system concepts identified as part of the Acquisition Strategy and included in Systems Engineering Plan (SEP).
F.3: Supplier Quality Management	Current state supplier quality management shortcomings for buy production system element supply chain sources on the Approved Supplier List (ASL) identified. Future state supplier quality management development needs in key manufacturing functional areas established and incorporated into the manufacturing CONOPS.	Supply chain quality management gaps associated with the current ASL and desired supply chain footprint identified and prioritized in terms of manufacturing CONOPS operational risk. Recommendations for broad types of alternative supply chain sources and supplier development solutions developed to address prioritized supply chain quality management gaps for buy production system elements associated with the future state industrial base footprint strategy.	Supply chain quality management gaps characterized for potential supply chain sources on the ASL that support the manufacturing CONOPS with recommendations for specific solutions to address the gaps provided along with supplier development assumptions, limitations, and boundary conditions. Industrial base operational requirements updated to incorporate supplier quality management requirements for buy production system elements associated with the desired industrial base footprint.	Potential supplier base quality capabilities and risks identified, including subtier supplier quality management. Supplier quality management technical requirements developed and used to down-select preferred sources for buy production system elements associated with the preferred system concept. Supplier development technical requirements established to address documented supply chain quality management gaps and incorporated into the manufacturing maturation plan (MMP).
G.1: Manufacturing Workforce (Engineering & Production)	Specialized manufacturing workforce skill set needs in key engineering and manufacturing functional areas identified along with shortcomings in current STEM and workforce development programs to deliver the needed human capital capabilities. Manufacturing CONOPS updated to establish linkages with ongoing STEM programs and regional workforce development initiatives for critical engineering and manufacturing skill set needs.	Specialized manufacturing workforce skill set gaps identified and prioritized in terms of manufacturing CONOPS operational risk. Recommendations for new types of STEM and workforce development training solutions and/or enhancements to ongoing programs identified that have the potential to deliver new human capital capabilities to support the future state manufacturing CONOPS.	Specialized manufacturing workforce skill set gaps characterized with specific STEM and workforce development solution recommendations provided on ways to improve the effectiveness and efficiency of ongoing and new programs to deliver the needed human capital capabilities. Industrial base operational requirements updated to incorporate specialized engineering and manufacturing skill sets required to support the manufacturing CONOPS.	Manufacturing skill sets associated with the types of system and manufacturing concepts being evaluated in the AoA identified and manufacturing workforce requirements (technical and operational) evaluated as part of AoA. Determine availability of process development workforce for the Technology Maturation and Risk Reduction Phase.
H.1: Tooling, Special Test and Inspection Equipment (STE/SIE)	Specialized tooling, special test equipment (STE), and special inspection equipment (STI) needs/requirements identified for material and/or process family/class specimen testing required to support hypothesis development to establish qualitative cause-effect relationships between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Specialized tooling, special test equipment (STE), and special inspection equipment (STI) needs/requirements identified for device family hardware testing required to support hypothesis validation to establish quantitative correlations between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Specialized tooling, special test equipment (STE), and special inspection equipment (STI) needs/requirements identified for part family component testing required to support analytical model development and validation for the quantitative prediction of cause-effect relationships between critical technology variables and design dependent parameters (e.g., producibility, manufacturability, material maturity, process maturity).	Tooling/Special Test Equipment (STE)/Special Inspection Equipment (SIE) requirements are considered for system concepts under consideration as part of AoA. Tooling/STE/STI development and validation needs for preferred system concepts identified and incorporated into the Systems Engineering Plan (SEP).
H.2 : Facilities	Specialized manufacturing and test facility capability and capacity needs and constraints for buy production system elements associated with the manufacturing CONOPS identified. Future state manufacturing and test facility capital investment areas to address capability and capacity need shortcomings evaluated and incorporated into the manufacturing CONOPS.	Specialized manufacturing and test facility capability and capacity gaps identified and prioritized based on manufacturing CONOPS operational risk. Recommendations for broad types of alternative facility and capital investment solutions developed for make production system elements to address prioritized facility capability and capacity gaps for make production system elements associated with the future state industrial base footprint strategy.	Specialized manufacturing and test facility capability and capacity gaps characterized with specific capital investment solutions identified to address the gaps along with return on investment estimates. Specialized facility capital investment operational requirements to support the industrial base footprint and manufacturing competitiveness strategies developed and incorporated into the manufacturing CONOPS.	Technical requirements for specialized facility capital equipment to address alternative system and manufacturing concepts developed and incorporated into the AoA. Availability of manufacturing facilities that meet capability and capacity technical requirements for prototype development and production evaluated as part of AoA.
I.1: Manufacturing Planning & Scheduling	Current state manufacturing competitiveness gaps identified along with forecasts for projected trends. Proactive approaches looking 3-5 years in the future defined that identify materiel (i.e., technology, capital, workforce) and non-materiel (i.e., quality, cost, location) solution investment areas and used to shape a high-level manufacturing competitiveness strategy.	Manufacturing competitiveness gaps identified and prioritized in terms of operational risk. Manufacturing competitiveness strategy refined with manufacturing technology roadmaps and investment budgets updated to incorporate materiel solution approaches and factory capital investment strategic plans updated to incorporate non-materiel solution approaches.	Manufacturing competitiveness gaps characterized with specific materiel and non-materiel solution recommendations developed and incorporated the manufacturing competitiveness strategy. Materiel solution recommendations incorporated into manufacturing technology roadmaps and non-materiel solution recommendations incorporated into factory capital planning.	Overall manufacturing strategy for the preferred system concept developed and integrated with acquisition strategy. Prototype schedule risk mitigation efforts incorporated into Acquisition Strategy. Factory capital investment budgets approved and have sufficient funding to implement non-materiel solutions into facility operations.
I.2: Materials Planning	Current state system operational capability shortcomings analyzed and used to identify relevant product and production system improvement opportunities from the standard program Work Breakdown Structure (WBS) templates for the system families used to deliver the capability (see MIL-STD-881C), Program WBS templates used to help identify potential system-level technology insertion opportunities for basic science and technology (S&T) efforts associated with understanding physical phenomena associated with addressing the operational capability gaps.	Prioritized system operational capability gaps analyzed and used to identify key product and production system element leverage points from the associated WBS templates down to the appropriate level in the system hierarchy (levels 4-6) for the types of candidate solution sets being considered. Program WBS templates used to help identify potential system element (levels 4-6) technology transition opportunities for practical applications of science and technology (S&T) efforts which may be speculative.	System operational capability gaps characterized, with the WBS templates used to develop potential product and production system candidate soultion set architectures and WBS-based system element capability improvement strategies that includes integrated design and manufacturing considerations. Program WBS templates used to help identify distinctive system-level technology insertion opportunities for the types of part family applications identified for practical applications of science and technology (S&T) development efforts.	Preliminary program WBS developed from templates that includes manufacturing planning considerations for preferred product and production system concepts (e.g., systems engineering, system test and evaluation, training, data, industrial facilities, peculiar support equipment) development needs for preferred system concepts. Technology ~~development article~~ demonstration vehicle component parts list developed for all science and technology (S&T) development efforts with associated procurement lead time estimates.

APPENDIX D
DHS MATRIX WITH EXIT CRITERIA

DESIGN-VANTAGE TECHNOLOGIES, LLC

Providing Clients a Design-Vantage℠ Advantage

Homeland Security

Program Management Model for Technology Readiness Level (TRL) Assessment

Technology Phase	Basic Research	Research to Prove Feasibility		Technology Development		Technology Demonstration	Operational Test and Evaluation		Production and Deployment	
	Scientific research begins the first steps toward applied research and development. Examples include paper studies of a technology's basic properties, exploration of a technical phenomenon, and definition of a technical concept. This level represents the origin of technology readiness.	Once basic principles are observed and proven repeatable, practical applications can be formulated. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies, device phenomenology, and experimentation.	Active research and development is initiated. This includes analytical and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated.	Basic technological components are integrated to establish that they will work together. Examples include integration of modules and components in the laboratory.	The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components and software.	Representative model or prototype system is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Prototype near, or at, planned operational system level. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.	Technology has been proven to work in its final form and under expected operational deployment conditions. In almost all cases, this TRL represents completion of system development. Examples include test and evaluation of the system in its intended system configuration and operational environment.	Actual application of the technology in its final form and under mission conditions, in accordance with the user's Concept of Operations.
	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Considerations	❑ Who is the program sponsor? ❑ Who is the end-user / customer? ❑ How will the program be funded? ❑ Has a Mission Needs Statement been developed? ❑ Has communication with end-users and customers to define requirements begun? ❑ Have preliminary operational requirements been defined? ❑ Has the Program Management Vision been developed? ❑ Has a Feasibility Study White Paper been developed? ❑ Is there an identified threat, emerging threat, vulnerability, or gap this project addresses? ❑ Have initial risks been identified?	❑ Have end-users participated in concept and requirements development? ❑ Has Feasibility Study been approved? ❑ Has an empirical or theoretical design solution been developed? ❑ Has an analytical study confirmed basic principles of the technology? ❑ Has an operational requirements analysis been constructed/conducted? ❑ Have system concept(s) / architectures been assessed? ❑ Has a Program Risk Assessment been conducted? ❑ Has a Program Cost Analysis been developed? ❑ Has a Preliminary Security Assessment been conducted?	❑ What technologies exist elsewhere within DHS S&T that may integrate with this program or technology? ❑ Have laboratory experiments proved the technology's physical validity? ❑ Is there a Risk Management Plan? ❑ Is there a Program Management Plan (PMP)? ❑ Are Program Cost Analyses updated? ❑ Are Operational Requirements being applied to Functional Requirements? ❑ Is the Systems Engineering Management Plan (SEMP) in draft? ❑ Is a Proof of Concept Planning document being developed? ❑ Are manufacturing and producability issues being assessed?	❑ Who will conduct Proof of Concept? ❑ Have technology components been integrated? ❑ Has the IPT been briefed on progress of the technology's development? ❑ Has the customer been briefed on the results of the Proof of Concept? ❑ Has the Functional Requirements Document been vetted with customer? ❑ Has the SEMP been finalized? ❑ Is a Test and Evaluation Master Plan (TEMP) being created? ❑ Has a Configuration Management Plan been developed? ❑ Are Risk Management Plan, PMP, and Program Cost Analysis updated? ❑ Is there a Quality Assurance Plan? ❑ Has the Program Transition Manager collaborated w/Technology Managers?	❑ Are updates to Risk Management Plan or Program Cost Analysis needed? ❑ Has the TEMP been updated? ❑ Has the SEMP been updated? ❑ Has the PMP been updated? ❑ Does a CONOPS exist? ❑ Is the Security Assessment updated? ❑ Have an OMB 300 and Acquisition Plan been completed? (if required) ❑ Has the IPT certified readiness for transition of the Technology? ❑ Has the Program Transition Manager assisted in the development of critical transition documentation? ❑ Has an Analysis of Alternatives been developed? ❑ Is Entry Criteria Checklist complete? ❑ Has the Program Definition Document (PDD) been approved? ❑ Have the S&T Director(s) approved the program's transition?	❑ Has the PDD been approved and signed by the required parties? ❑ Has a Program Manager been identified? ❑ Are updates required to the Risk Management Plan, Program Cost Analysis, or PMP? ❑ Have the SEMP and TEMP been updated? ❑ Is testing and evaluation in a simulated operational environment planned? ❑ Is the end-user / customer still heavily involved in requirements refinement? ❑ Have initial Security Guidelines been developed? ❑ Are updates required to the Analysis of Alternatives? ❑ Are regulatory reports/tools required (NEPA, PART, Interoperability, etc.)?	❑ Have S&T and end-users begun to develop final transition documents? ❑ Is the Technology being demonstrated in an operational environment? ❑ What updates to the Operational and/or Functional Requirements Documents are necessary as a result of operational environment demonstration? ❑ Have the Risk Management Plan, Program Cost Analysis, and PMP been updated? ❑ Are Strategic Program Plan steps (e.g., Balanced Scorecard) complete? ❑ Has an Operations and Maintenance Manual been developed? ❑ Has a Security Manual been written? ❑ Will Interoperability be demonstrated? ❑ Have Management Directives (MD) been assessed for applicability?	❑ Has all technology functionality been demonstrated in an operational environment? ❑ Are all technology components form, fit, and function compatible with an operational system? ❑ How has production been addressed with end-users, customers, budgeters? ❑ Has the Transition Plan been finalized with end-users / customers? ❑ Has a Training Plan been developed? ❑ Has an Operational Test Report been created? ❑ Has a Limited User Test (LUT) Plan been developed?	❑ When will the first technology component or unit be fielded? ❑ Is planning underway for integration of next generation technology? ❑ Has the Training Plan been implemented? ❑ Has a Lessons Learned document been developed? ❑ Has an After Action Review been conducted? ❑ Have metrics been developed to measure sustained performance? ❑ Has a Sustainment Plan been completed?
Exit Criteria	✓ A program sponsor has been identified ✓ Program end-users / customers have been identified ✓ A Mission Needs Statement has been developed ✓ Communication with end-users and customers has been initiated ✓ Preliminary operational requirements have been defined ✓ Program Management Vision has been developed ✓ A Feasibility Study White Paper has been developed ✓ A threat, vulnerability, or gap has been identified ✓ Initial risks have been identified ✓ (List other Exit Criteria when defined)	✓ The end-user is involved in concept and requirements development ✓ The Feasibility Study has been accepted ✓ An empirical or theoretical design solution has been identified ✓ Analytical studies to confirm the basic principles of the technology have been developed ✓ Operational requirements analysis has been conducted ✓ System concept(s) / architectures have been assessed ✓ A Program Risk Assessment has been conducted ✓ The Program Cost Analysis has been completed ✓ A Preliminary Security Assessment has been conducted	✓ Supplemental and alternate technologies throughout DHS S&T have been surveyed ✓ The technology's physical validity has been proven in laboratory experiments ✓ A Risk Management Plan has been developed ✓ A Program Management Plan (PMP) has been developed ✓ The Program Cost Analysis has been updated ✓ Operational Requirements are being applied to Functional Requirements ✓ The Systems Engineering Management Plan (SEMP) is being drafted ✓ The Proof of Concept Plan has been developed ✓ A manufacturing / production strategy has been developed	✓ All required technology components are integrated for Proof of Concept ✓ Proof of Concept is conducted ✓ The IPT has been briefed on progress of the technology's development ✓ The customer has been briefed on the Proof of Concept results ✓ The Functional Requirements Document has been finalized ✓ The SEMP has been finalized ✓ The TEMP has been completed ✓ Configuration Management Plan exists ✓ The PMP has been updated ✓ The Risk Management Plan is updated ✓ The Program Cost Analysis is updated ✓ A Quality Assurance Plan exists ✓ The Program Transition Manager is engaged in transition planning	✓ The Risk Management Plan is updated ✓ Program Cost Analysis is updated ✓ The SEMP, TEMP and PMP are updated ✓ A CONOPS is developed ✓ The Security Assessment is updated ✓ An OMB 300 and Acquisition Plan have been completed (if required) ✓ The IPT has certified readiness for the transition of the Technology ✓ The Program Transition Manager has assisted in transition documentation development ✓ Analysis of Alternatives is developed ✓ The Entry Criteria Checklist is completed and delivered to the TM ✓ The PDD has been created/completed ✓ Director has approved the transition	✓ The PDD has been approved and signed ✓ A Program Manager has been identified ✓ The Risk Management Plan, Program Cost Analysis, and PMP have been updated ✓ The SEMP and TEMP are updated ✓ Successful testing and evaluation in a simulated operational environment has been conducted ✓ The end user / customer has been briefed on the results of the testing ✓ Initial Security Guidelines have been developed ✓ Analysis of Alternatives is updated ✓ A draft Program Assessment Rating Tool (PART) plan exists, if required ✓ National Environmental Policy Act (NEPA) plan / assessment, if required ✓ Interoperability Assessment	✓ S&T and the end-user / customer have begun to develop final transition planning documentation ✓ The Technology is being demonstrated in an operational environment ✓ Updates (if required) have been made to the Operational and/or Functional Requirements Documents ✓ The Risk Management Plan, Program Cost Analysis, and PMP have been updated (as needed) ✓ Strategic Program Planning (e.g., Balanced Scorecard) has been conducted ✓ The Operations and Maintenance Manual has been completed/updated ✓ A Security Manual has been developed ✓ Interoperability has been demonstrated ✓ Management Directives (MD) have been reviewed to assure compliance	✓ The technology has been successfully demonstrated in an operational environment ✓ All technology components are form, fit, and function compatible with an operational system ✓ Technology production has been addressed and planned by DHS and the end-user / customer ✓ A Transition Plan has been developed ✓ Training Plan has been developed ✓ The Operational Test Report has been completed ✓ A Limited User Test (LUT) Plan has been developed	✓ All critical program documentation has been completed ✓ Planning is underway for the integration of the next generation technology into the existing program components ✓ End-user fully demonstrates the technology in CONOPS ✓ Training Plan is implemented ✓ Lessons Learned completed ✓ After Action Review completed ✓ Sustainment Plan is completed
Key Deliverables [1]	➢ Mission Identification Statement ➢ Feasibility Study (White Paper) ➢ Program Management Vision, or ➢ Description of Leap-ahead Capability ➢ (List other Deliverables when defined)	➢ Operational Requirements Document (end-user / customer validation) ➢ Program Cost Analysis ➢ Program Risk Assessment (technology, schedule, etc.) ➢ Preliminary Security Assessment	➢ Risk Management Plan ➢ Program Cost Analysis (updated) ➢ Functional Requirements (draft) ➢ Systems Engineering Management Plan (SEMP) draft ➢ Proof of Concept Plan ➢ Program Management Plan (PMP) draft ➢ End-user / Customer Status Review	➢ Proof of Concept Report ➢ Functional Requirements Document ➢ SEMP ➢ TEMP ➢ Quality Assurance Plan ➢ Configuration Management Plan ➢ PMP (updated) ➢ Risk Management Plan (updated) ➢ Program Cost Analysis (updated) ➢ End-user / Customer Status Review	➢ CONOPS ➢ TEMP (updated) ➢ SEMP (updated) ➢ PMP (updated) ➢ Risk Management Plan (updated) ➢ Program Cost Analysis (updated) ➢ Security Assessment (updated) ➢ Program Definition Document (PDD) [3] ➢ OMB 300 Capital Asset Plan [3] ➢ Acquisition Plan ➢ Entry Criteria Checklist ➢ Analysis of Alternatives	➢ TEMP (updated) ➢ SEMP (updated) ➢ PMP (updated) ➢ Risk Management Plan (updated) ➢ Program Cost Analysis (updated) ➢ Initial Security Guidelines ➢ Analysis of Alternatives (updated) ➢ Draft Program Assessment Rating Tool (PART) plan, if required ➢ National Environmental Policy Act (NEPA) initial assessment, if required ➢ Interoperability Assessment	➢ Transition Plan (draft) ➢ Operational and Functional Requirements Documentation (updated) ➢ Risk Management Plan (updated) ➢ Program Cost Analysis (updated) ➢ PMP (updated) ➢ Strategic Program Planning Documentation (if conducted) ➢ Operations and Maintenance Manual ➢ Security Manual ➢ Interoperability Assurance Report ➢ Applicable Management Directives (MD), if required	➢ Limited User Test (LUT) Plan ➢ Deployment or Transition Plan ➢ Training Plan ➢ Operational Test Report ➢ Final Interoperability Assurance Report ➢ Customer Acceptance Document ➢ Initial Systems-level Metrics Assessment	➢ Customer Feedback ➢ Lessons-Learned ➢ After-Action Review ➢ Sustainment Plan - Spiral Development Assessment - Preplanned Product Improvement - Emerging Threat(s) Assessment - Technology Refresh / Insertion - Quality Assurance / Metrics Report - Risk Management Reassessment

Notes:

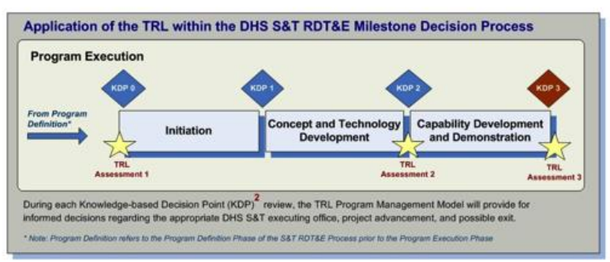
1 – The Key Deliverables listed have been established as an optimized set for a notional program. The exact portfolio of Key Deliverables and Exit Criteria will vary on a program-by-program basis.

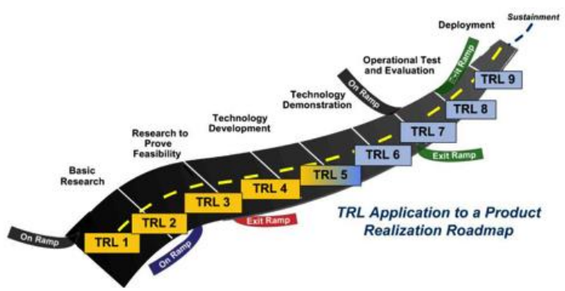
2 – Knowledge-based Decision Points are adapted from the "Knowledge-based Acquisition Approach" outlined in the GAO Report entitled *Further Action Needed to Promote Successful Use of DHS Acquisition Authority* (GAO-05-136), as well as the GAO Best Practices Report entitled *Highlights of the Knowledge-based Approach Used to Improve Weapon Acquisition* (GAO-04-392SP).

3 – Although the DHS S&T Program Definition Document (PDD), is associated with TRL 5 in this model, a PDD may also be a deliverable for Knowledge-based Decision Point 1, or may be created at any TRL prior to the program's transition. The OMB 300 Capital Asset Plan and Acquisition Plan, if required through the DHS Investment Review Process, may be delivered at any TRL prior to transition.

Programs are evaluated on a case-by-case basis to determine when:
- Required deliverables and critical documentation are to be developed;
- Customers will approve of the deliverables and results demonstrated; and
- Relationships will be developed to facilitate successful technology transfer.

Technology Readiness Levels and their associated definitions were first presented by John C. Mankins of NASA's Office of Space Access and Technology in a white paper dated April 6, 1995.





U.S. Department of Homeland Security
Science and Technology Directorate

Dr. Charles E. McQueary - Under Secretary
DHS Science and Technology
Washington, DC 20528

September 1, 2005
Version 1.0
Sheet 1 of 1

Dr. Kirk Evans – Acting Director, Office of Programs, Plans, and Requirements

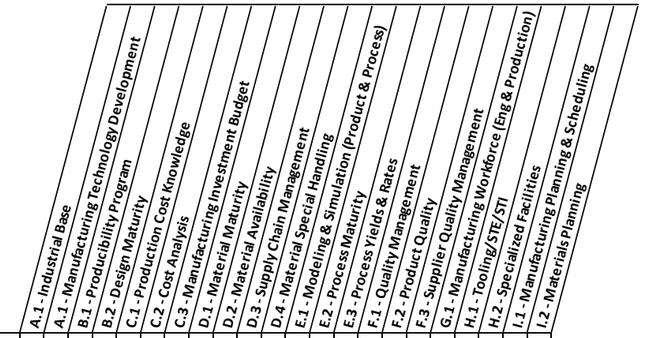
Dr. Maureen McCarthy – Director, Office of Research and Development

Mr. John J. Kubricky – Director, Office of Systems Engineering & Development and Acting Director, Homeland Security Advanced Research Projects Agency

Mr. Victor Tambone – Chief of Staff, Science & Technology Directorate

APPENDIX E
DHS TRL 1-4 THREAD MAPPING TO MRL THREADS

DHS TRL 1 EXIT CRITERIA	DHS TRL 2 EXIT CRITERIA	DHS TRL 3 EXIT CRITERIA	DHS TRL 4 EXIT CRITERIA
Early SE-to-S&T Linkages (Tech Transition)	***Early SE-to-S&T Linkages***	***Early SE-to-S&T Linkages***	***Early SE-to-S&T Linkages***
Program end users /customers have been identified			The customer has been briefed on proof of concept results
A threat, vulnerability, or gap has been identified	A preliminary security assessment has been completed => Impact analysis and business case	Supplemental and alternate technologies throughout DHS S&T have been surveyed	The program transition manager is engaged in transition planning
Early S&T TRL Elements	***Early S&T TRL Elements***	***Early S&T TRL Elements***	***Early S&T TRL Elements***
A feasibility study white paper has been developed	The feasibility study has been accepted	The proof of concept plan has been developed => plan to get from TRL 3 to TRL 4	Proof of concept is conducted
	Analytical studies to confirm the basic principles of the technology have been developed	The technology's physical validity has been proven in laboratory experiments	All required technology components are integrated for proof of concept
	An empirical or theoretical design solution has been identified => invention begins		
Early SE DP Elements	***Early SE DP Elements***	***Early SE DP Elements***	***Early SE DP Elements***
Preliminary operational requirements have been defined	Operational requirements analysis has been conducted	Operational requirements are being applied to functional requirements	The functional requirements document has been finalized
A mission needs statement has been developed	System concept(s) / architectures have been assessed		Configuration management plan exists
Communication with end-users and customers has been initiated	The end-user is involved in concept and requirements development		
		The systems engineering management plan (SEMP) is being drafted	The SEMP has been finalized
MODELING & SIMULATION APPROACH TO SUPPORT DIGITAL THREAD ACROSS LIFE CYCLE			
Early PM Elements	***Early PM Elements***	***Early PM Elements***	***Early PM Elements***
A program sponsor has been identified			The IPT has been briefed on progress of the technology's development
	The program cost analysis has been completed	The program cost analysis has been updated	The program cost analysis is updated
Initial risks have been identified	A program risk assessment has been conducted	A risk management plan has been developed	The risk management plan has been updated
Program management vision has been developed		A program management plan (PMP) has been developed	The PMP has been updated
Early Manufacturing Elements	***Early Manufacturing Elements***	***Early Manufacturing Elements***	***Early Manufacturing Elements***
		A manufacturing / production strategy has been developed	
			A quality assurance plan exists
EARLY ADVANCED MANUFACTURING ENTERPRISE DESIGN AND ANALYSIS			
EARLY PROCESS CAPABILITY EVALUATIONS, BENCHMARKING, AND BASELINES			
EARLY MATERIALS PLANNING AND LONG LEAD PROCUREMENT ANALYSES			
Early T&E Elements	***Early T&E Elements***	***Early T&E Elements***	***Early T&E Elements***
			The TEMP has been completed



APPENDIX F
DRAFT MRL 1-3 THREAD OBJECTIVES FOR EARLY SE AND EARLY S&T

MRL 1-3 knowledge development focus areas for early systems engineering (SE) and early science and technology (S&T) basic research (6.1) and applied research (6.2) activities:

- A.1: Industrial Base (Production System, Assessing/Evaluating)
  - Early SE –Industrial Base Capability and Vulnerability Baselines and Benchmarks
  - Early S&T -
- A.2: Manufacturing Technology Development (Product-Production, Planning/Executing)
  - Early SE –
  - Early S&T -
- B.1: Producibility Program (Product-Production, Analyzing/Understanding)
  - Early SE – System Producibility and Manufacturability Requirements Analysis
  - Early S&T – Relative Producibility Impact Analyses Associated with Technology
- B.2: Design Maturity (Product System, Assessing/Evaluating)
  - Early SE – System Operational Requirements and Concept Development
  - Early S&T –Technology Design Methods/Tools Requirements Development
- C.1: Production Cost Knowledge (Product-Production, Analyzing/Understanding)
  - Early SE – Affordability Requirements and System LCC Leverage Point Analyses
  - Early S&T – Preliminary Technology Insertion Cost Savings Model Development
- C.2: Cost Analysis (Product System, Assessing/Evaluating)
  - Early SE – "Similar-to" System Concept Cost Baselines and Benchmarks
  - Early S&T –Potential Technology Transition Pathways and Cost-Benefit Studies
- C.3: Manufacturing Investment Budget (Product-Production, Planning/Executing)
  - Early SE –
  - Early S&T -
- D.1: Material Maturity (Product System, Analyzing/Understanding)
  - Early SE – Material Knowledge Base Development Requirements
  - Early S&T – Material Processing-Structure-Property Relationships
- D.2: Material Availability (Product System, Planning/Executing)
  - Early SE – Proactive Critical Material, Obsolescence, and DMSMS Planning
  - Early S&T –
- D.3: Supply Chain Management (Production System, Assessing/Evaluating)
  - Early SE – Supply Chain Capability and Capacity Baselines and Benchmarks
  - Early S&T -
- D.4: Material Special Handling (Product System, Planning/Executing)
  - Early SE –
  - Early S&T -
- E.1: Modeling & Simulation (Product-Production, Assessing/Evaluating)
  - Early SE – Model Based Systems Engineering Approach for Products and Processes
  - Early S&T -
- E.2: Manufacturing Process Maturity (Production System, Analyzing/Understanding)
  - Early SE –
  - Early S&T – Process Stability and Repeatability Cause-Effect Relationships
- E.3: Process Yields & Rates (Production System, Assessing/Evaluating)
  - Early SE – Manufacturing Process Yield and Rate Baselines and Benchmarks

  - Early S&T – Manufacturing Defect and Design-Processing Parameter Correlations
- F.1: Quality Management (Production System, Assessing/Evaluating)
  - Early SE –
  - Early S&T -
- F.2: Product Quality (Product System, Planning/Executing)
  - Early SE – System Concept Verification & Validation Approach and Criteria
  - Early S&T – Technology Verification & Validation Approach and Criteria
- F.3: Supplier Quality Management (Production System, Assessing/Evaluating)
  - Early SE –
  - Early S&T –
- G.1: Manufacturing Workforce (Production System, Assessing/Evaluating)
  - Early SE – Functional Skill Set Competency Baselines and Benchmarks
  - Early S&T – Technology Specific Skill Set Competency Requirements
- H.1: Tooling/STE/STI (Product System, Planning/Executing)
  - Early SE –
  - Early S&T – Experimental HW Fabrication Tooling/STE/STI Requirements
- H.2: Facilities (Production System, Assessing/Evaluating)
  - Early SE – Specialized Production/Test Facility Baselines and Benchmarks
  - Early S&T – Specialized Experimental HW Fabrication/Test Facility Requirements
- I.1: Manufacturing Planning & Scheduling (Production System, Planning/Executing)
  - Early SE –
  - Early S&T -
- I.2: Materials Planning (Product-Production, Planning/Executing)
  - Early SE –
  - Early S&T -