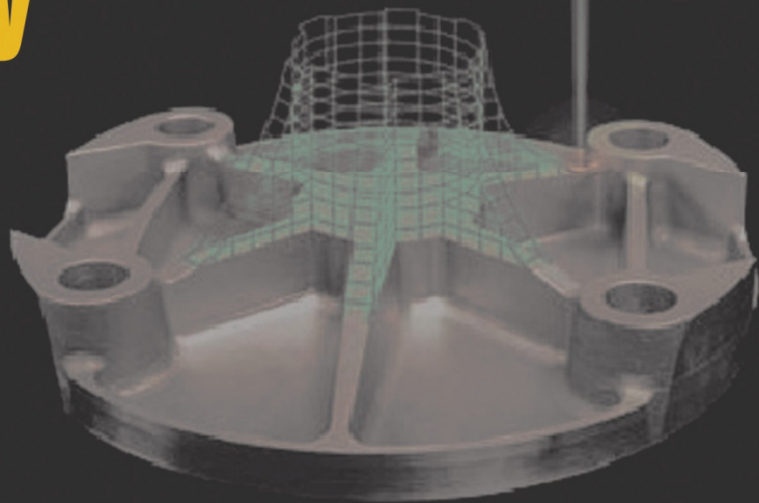


Rapid Capability Fielding “Toolbox” Study



Final Report



March 2010

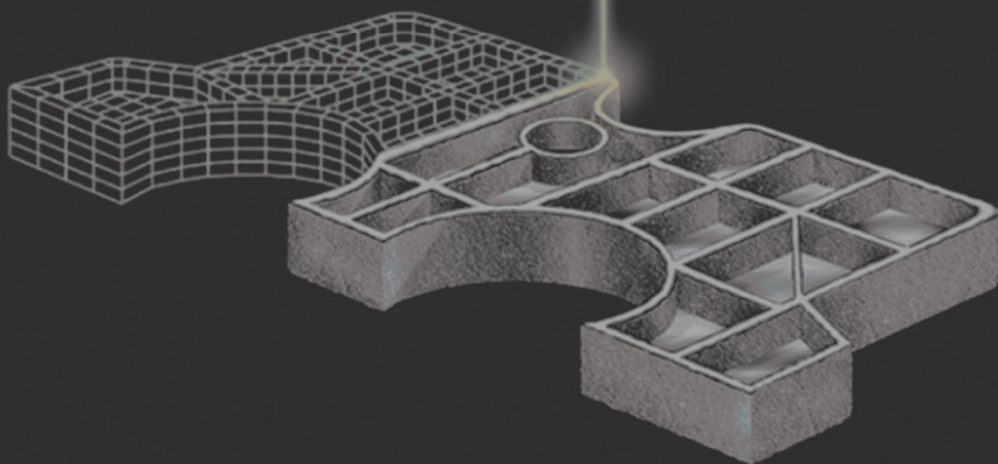


Table of Contents

EXECUTIVE SUMMARY	III
BACKGROUND	III
STUDY OBJECTIVE.....	III
FINDINGS.....	III
PRINCIPAL RECOMMENDATIONS.....	IV
I. BACKGROUND.....	1
A. DEFINITION OF “RAPID” CAPABILITY FIELDING PROGRAMS	1
B. TERMS OF REFERENCE	1
C. OBJECTIVES FOR RAPID FIELDING	2
D. MEASURING SUCCESS WHEN APPLYING “TECHNOLOGY TOOLS”	3
E. STUDY METHODOLOGY.....	3
II. OBSERVATIONS AND FINDINGS	5
A. GENERAL OBSERVATIONS ABOUT RAPID FIELDING PROGRAMS	5
B. LEVERAGE POINTS IN RAPID CAPABILITY FIELDING PROGRAMS.....	8
C. IMPACT OF THE SPECTRUM OF RAPID CAPABILITY FIELDING CHALLENGES.....	9
D. ENGINEERING	9
1. Engineering and Execution Strategy	9
2. Crosscutting Engineering Challenges	11
3. Engineering Tool Trends.....	12
E. MODELING AND SIMULATION:	16
F. MANUFACTURING	18
G. USER-CENTERED DESIGN	20
H. SUMMARY OF FINDINGS.....	21
III. TOOL-ENABLED RAPID CAPABILITY DEVELOPMENT	22
A. CONCEPT ENGINEERING	22
1. Concept Engineering Tools.....	24
2. Concept Engineering Recommendations.....	26
B. CAPABILITY ENGINEERING	27
1. Capability Engineering Tools	28
2. Capability Engineering Recommendations	28
C. POTENTIAL PILOT PROJECTS.....	29
1. Forward Operating Base Protection.....	29
2. Other Recommended Pilots	30
CONCLUSIONS.....	31
APPENDIX A: TERMS OF REFERENCE	35
APPENDIX B: PANELISTS.....	38
APPENDIX C: INFORMATION GATHERED BY THE STUDY PANEL	41
APPENDIX D: RAPID FIELDING CASE-STUDY – WARLOCK BLUE	44

APPENDIX E: SYSTEM AND SOFTWARE CONSORTIUM WORKSHOP SUPPORTING THE RAPID FIELDING STUDY	47
APPENDIX F: USER-CENTERED DESIGN	52
APPENDIX G: DFX TOOLS	54
APPENDIX H: HIERARCHICAL ABSTRACTION AND AUTO-DESIGN TOOLS	55
APPENDIX I: USE OF VIRTUAL REALITY (VR) IN TRAINING ENVIRONMENTS.....	57

Executive Summary

Background

In the current conflicts in Iraq and Afghanistan, U.S. adversaries have demonstrated the ability to rapidly adopt and adapt widely-available globalized technologies and systems to conduct irregular warfare. The standard Department of Defense acquisition process is not designed to respond to this extremely dynamic environment, creating the need for more rapid development capabilities. In response, the Department has embarked on multiple rapid capability initiatives and has, in many cases, succeeded in providing critical capabilities to the warfighter, in spite of the challenges associated with a culture and acquisition system ill-suited to the task. Significant changes in policies, processes, and culture are required to institutionalize the effective and efficient development and execution of rapid capability projects. The required policy, process, and cultural changes have been the topic of studies in the recent past.^{1,2} The Director of Defense Research and Engineering (DDR&E), Mr. Lemnios, chartered this 60-day study to view the rapid capability challenges through a different lens: *a technical one*. This study explores the adoption, development, and implementation of new technological tools to enable better end-to-end execution of rapid capability projects. In addition, it provides specific recommendations to the DDR&E regarding technological opportunities to significantly decrease the development time and increase the operational effectiveness of rapidly fielding capabilities.

Study Objective

This rapid turnaround (60 days) study provides recommendations to the Director, Defense Research and Engineering (DDR&E) regarding technological opportunities to significantly decrease the development time and increase the operational effectiveness of rapidly fielded capabilities. Current and emerging tools that defense and commercial industries use were evaluated for their potential application to rapid capability fielding projects. The study specifically focused on three types of tools: (1) modeling and simulation (M&S) tools to support rapid design, fabrication, and testing; (2) systems engineering (SE) tools to support rapid design and re-design of complex systems; and (3) manufacturing tools to reduce the total time to manufacture.

Findings

Concept Engineering. Significant opportunities exist to develop and deploy technologies that strengthen the Department of Defense's (DoD's) ability to conduct rapid capability fielding. The greatest and most immediate opportunities are in the early portion of the development life cycle, spanning the time from the emergence of a need to the beginning of detailed design. A term was coined for this portion of the development life cycle: *concept engineering*. This phase offers the greatest leverage in applying technology tools to better execute rapid capability fielding projects.

Tools are available or are in development that could be applied in the concept engineering phase to reduce the time required to elucidate or anticipate needs, and provide for a richer, more in-depth

¹ Defense Science Board, *Creating an Effective National Security Industrial Base for the 21st Century: An Action Plan to Address the Coming Crisis*, DSB Task Force Report. July 2008.

² Defense Science Board, *Fulfillment of Urgent Operational Needs*, DSB Task Force Report. July 2009.

understanding of the context of operational requirements and human factors. These tools could also speed the exploration of the material and non-material aspects of alternative solutions. Two specific technology areas that could have great impact are *virtual environments* (including gaming) and *rapid physical prototyping systems*. Virtual environments have been used to great effect in the DoD training and mission rehearsal communities but have not been fully exploited to support the concept engineering phase of the development life-cycle. Rapid physical prototyping technologies continue to mature and should become a critical and commonplace tool used in a wide-variety of projects. Increased use of these technologies in the concept engineering phase could substantially impact the rapid understanding of the utility of specific solution concepts; enable the rapid and simultaneous development of concepts of operation (CONOPS) and Tactics, Techniques, and Procedures (TTPs); support early red teaming to ensure solution robustness; and mitigate problems downstream in the design, test, build, sustainment, and transition of candidate solutions. In addition to these two specific families of tools, the study also identified user-centered design tools, processes and educational resources to assist in the rigorous identification and development of the often hidden needs through direct engagements with the warfighters in the field. Finally, the closed-loop and iterative use of virtual prototyping, physical prototyping, and user-centered design, in a fashion that simultaneously includes developers and users, would constitute a powerful concept engineering environment.

Capability Engineering. Opportunities also exist to increase design, test, and production efficiencies once a conceptual design is chosen. The study used the term *capability engineering* to encompass this phase of the development cycle. In many cases, commercial industry's more rapid product development cycles are driving technology advances in these areas. Many of the emerging tools, sometimes thought of under the discipline of "model-based engineering," achieve efficiencies through the application of abstractions, design rules, and design libraries. These tools achieve significant reductions in the time-to-design, time-to-test, and time-to-manufacture by restricting the global design options, or in the case of software through greater dependence on advanced code generation capabilities that produce code directly from high level models and / or structured English language specifications. These tools are typically applied in a systems engineering process that is tailored to meet the needs of the particular project at hand. Model-based engineering developments could have an impact across all Department programs. For rapid capability projects, where many solutions amount to modifications or adaptations of existing military assets, model-based engineering could substantially impact the speed and accuracy with which such solutions could be fielded.

Cultural Change. The application of technology to improve the capabilities to rapidly develop and field solutions is significant. However, technology alone will not result in the desired end-state. To fully institutionalize rapid capability fielding, non-technical challenges such as cultural, budgetary, contracting, etc. must be appropriately addressed. A systematic implementation of both technical and non-technical solutions will significantly enhance the department's rapid fielding of capabilities.

Principal Recommendations

1. Concept Engineering Center. The DDR&E should immediately sponsor a concept engineering center to serve as a focal point for the development of concept engineering strategies, techniques, tools, and methods. Such a center would serve as a "proving ground" for concept

engineering and would transition best practices, tools, etc., to the DoD community (Military Services, federally-funded research and development centers (FFRDCs), and contractors). This center should inventory and leverage the substantial capabilities currently existing across the department in M&S (game and virtual environment development) and rapid prototyping, and establish deep ties with the combatant commander communities.

2. R&D Roadmap. The Department of Defense should develop and implement a strategic research and development (R&D) roadmap to guide the development, maturation, tailoring, and transition of emerging tools specifically focused on supporting the execution of rapid capability fielding projects. The roadmap should address all relevant tools that span the entire development life cycle—from concept engineering through sustainment.
3. Pilot Programs. Pilot programs should be immediately implemented to demonstrate the application of today's technology toolset to relevant rapid capability fielding challenges and to provide feedback for future tool development. The panel's primary recommendation is to initiate a Forward Operating Base (FOB) protection pilot to demonstrate the applicability of user-centered design, virtual reality, gaming, prototypes, and CONOP/TTP development and assessment. Four others potential candidates are also offered: a multi-purpose, adaptable unmanned aerial vehicle (UAV), to demonstrate model-based engineering used to enable rapid platform adaptability; exploration of specific Intelligence, Surveillance and Reconnaissance (ISR) sensor and exploitation system options; a demonstration of concept engineering and red teaming to examine offensive and defensive aspects of swarming unmanned vehicles; and a virtual and physical prototyping environment for hand-carried devices used in maritime boarding operations to collect biometrics and electronic media.

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I. Background

The Department of Defense's (DoD) acquisition process, governed by the DoD 5000-series directives, generally requires several years—sometimes decades—to field a capability when measured from the time a requirement is first identified.³ While this process has met the department's needs in the past, the current conflicts in Iraq and Afghanistan have highlighted the need to also have processes for more rapidly developing and fielding solutions.

This study follows a number of recent DoD studies on how to improve the department's ability to more rapidly field capabilities. The key differentiator between this study and previous efforts is its focus on *technology-based tools* that are, or could be, used by rapid acquisition programs. Previous studies focused on the non-technological areas that inhibit the department's ability to rapidly field capabilities, such as formalized requirements processes, funding constraints, personnel, and culture. The recommendations of this technology tools study complement those of prior studies and taken together provide a comprehensive roadmap for institutionalizing effective rapid fielding capability.

A. Definition of “Rapid” Capability Fielding Programs

The Department of Defense does not have a formal definition for the term *rapid capability fielding* programs; however, there is a general sense that rapid fielding programs deliver capabilities within a two-year window (and often much less than that). Fielding within two years is shorter than the lead time to simply budget for normal acquisition programs. This study, therefore, adopted the “two year” definition of a rapid fielding program. The study assumed that the two years begins at the time when a need emerges in the field and concludes at the initial capability fielding date. The transition to a program of record, where appropriate, typically occurs beyond this two year window, but the study also considered transition needs.

B. Terms of Reference

The primary objective of this study was to provide specific recommendations to the Director, Defense Research and Engineering (DDR&E) regarding technological opportunities to significantly decrease the development time and increase the operational effectiveness of rapidly fielded capabilities.

DDR&E provided a list of questions to be addressed, which are discussed throughout this report:

1. **What are the current technical tools used in both the defense and commercial industries to rapidly design, fabricate, test, and validate new systems?** Specifically, DDR&E was interested in modeling and simulation tools to support rapid design, fabrication, and testing; system engineering tools to rapidly design and redesign complex systems; and manufacturing processes and tools to speed development. In addition, the study should determine whether there are tools that allow for end-to-end rapid development, including functions such as CONOPS development, interoperability, and testing.

³ GOA-08-674T, *Results of Annual Assessment of DoD Weapon Programs*, reports that in 2001-2008, the average time spent just in system development for major acquisition programs averaged 37 months. This does not include time spend in requirements development, concept development, manufacturing, fielding, etc.

2. **What are the current capabilities and limitations for addressing DoD rapid fielding capabilities needs for each of the tools examined?**
3. **What are the emerging technological opportunities?** The study requires identification of the technical leaders in these areas and must propose approaches to validate the impact of these tools.
4. **What are the best methods for developing these technology opportunities?** This should include discussion of the program scope, scale, and schedule required to support this development, suggestions as to how this might be accomplished, and by whom.
5. **What are the options for immediate improvement of rapid capability delivery?** The report should recommend a method for tailoring current tools, techniques, models, methodologies, best practices, etc., to achieve better rapid fielding of capabilities immediately, if possible.

The complete terms of reference are included at Appendix A.

C. Objectives for Rapid Fielding

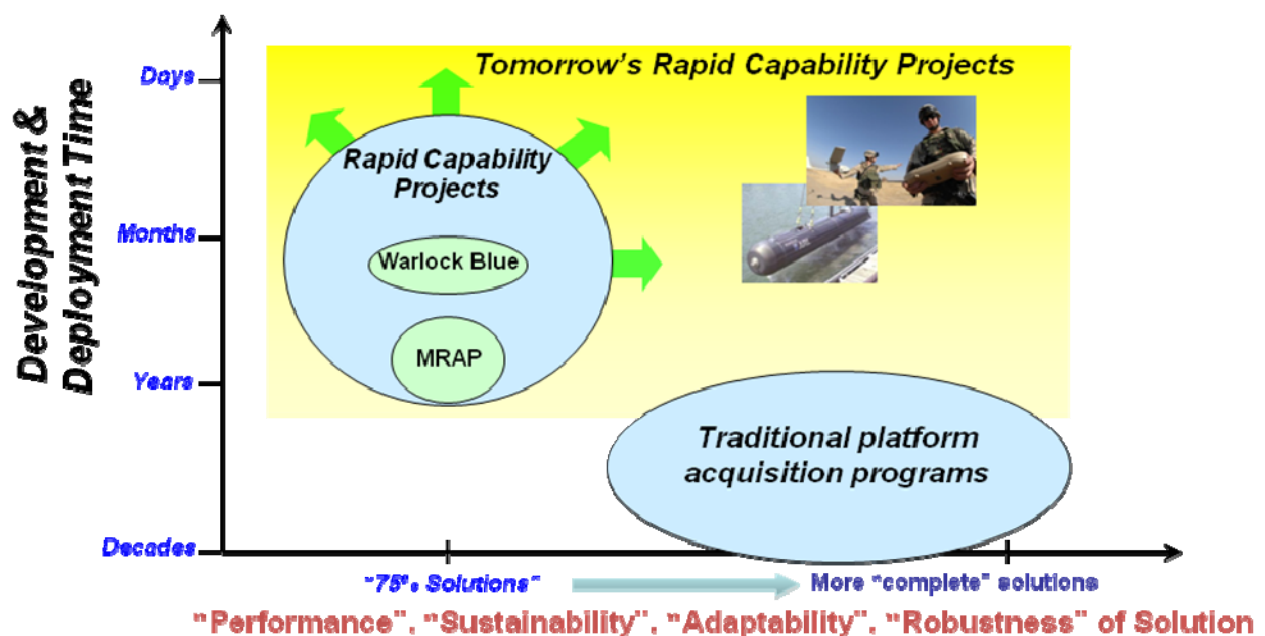


Figure 1: Depiction of rapid capability programs compared to traditional acquisition programs.

Figure 1 compares traditional acquisition programs and rapid capability programs in terms of development time and solution “completeness.” It is important to note that traditional acquisition programs are structured to provide solutions that are complete in the sense of meeting all operational effectiveness and suitability requirements and are designed for a long life cycle. Often this increased completeness is captured in improved “-ilities” such as maintainability, reliability, etc. and other non-technical support aspects such as training, manuals, etc. In contrast, rapid capability fielding projects

may deliberately trade away completeness in the interest of speed. These “75% solutions” provide capability within months to a few years⁴, but they may not deliver the full performance desired in a long term solution, or they may be incomplete in that they do not completely address the “-ilities”. Rapidly-fielded systems may be large, such as the Mine-Resistant Ambush Protected (MRAP) vehicle, or small, like the Warlock Blue handheld jammer. A key goal in this study was to identify tools that, if applied to rapid capability fielding projects, will not only decrease the time required to develop and field solutions, but also increase the performance, sustainability, adaptability, and robustness of the solution—as indicated in the arrows in Figure 1 for tomorrow's rapid capability fielding projects.

D. Measuring Success When Applying “Technology Tools”

For the purpose of this study, technology tools are defined to include software, algorithms, models, simulations, manufacturing hardware and software, and associated processes that support the full life-cycle of rapid development. Technology tools can have a multiplicity of simultaneous effects on the rapid fielding of capabilities. The first is a direct reduction of the time required to complete individual steps in the life-cycle. A closely related effect is to reduce the number of iterations of “design-build-test-produce-field” required to converge on an effective capability. Finally, the tools are meant to ensure that the design truly meets all aspects of the original and sometimes evolving in-theater need. These three effects are interdependent and can often be supported through the use of the same technology tools.

In addition to shortening the time needed to field a solution, technology tools can improve the ability to anticipate urgent needs and, if possible, to preempt them. Technology tools can help ensure that solutions adequately address the *real* need, that they have the appropriate support, and that they have the desired operational longevity. Fielding an inadequate solution or belatedly deciding that the solution needs to be supported for a prolonged period often means starting over again.

Another desired effect of technology tools is to make rapid capability fielding more routine, not a series of heroic ad hoc efforts that, while commendable, soon exhaust the development teams.

Finally, technology tools used early in the rapid capability fielding effort can ease transition to a program of record (POR) when the need dictates. Tools for efficiently capturing and documenting the detailed requirements, and those specifically tailored to address reliability, maintainability, safety engineering, logistics planning, and training package development fall in this category.

E. Study Methodology

A panel of subject matter experts (SMEs) conducted this study (Appendix B), informed by interactions with executives, program managers and researchers from government, industry and academia. The panelists met for three multi-day workshops, and three multi-hour teleconferences to discuss the as-is state of the rapid fielding of capabilities, to examine defense and commercial rapid fielding projects, and to develop recommendations on how to improve the current system by applying technology tools to better facilitate rapid fielding. In addition to the formal workshops and teleconferences, panelists

⁴ Garamone, Jim. “Procurement Reform Must be Government Priority, Gates Tells Senate.” 27 January 2009. American Forces Press Service. 25 January 2010. <<http://www.defense.gov/news/newsarticle.aspx?id=52838>>

collected inputs from other SMEs within the federal government, academia, and industry in other settings. The government perspectives provided to the panel included views from the Services' chief systems engineers, from rapid fielding organizations in various DoD components, and from R&D programs developing tools and technologies for engineering, manufacturing, and modeling and simulation. The industry and academic perspectives included views from hardware and software companies (defense and commercial, large and small), a workshop conducted by the Systems and Software Consortium, and views from prominent university researchers in engineering and modeling disciplines and in the area of user-centered design. A list of SMEs that made presentations to, or were consulted by, the panel is included as Appendix C.

This was a rapid turn-around study. The team attempted to be as inclusive as possible. However, some relevant rapid fielding efforts—which would have provided additional insights into technical tools and methods—were not included due to time constraints.

II. Observations and Findings

While technology tools are the focus of this study, it is critical to remember that technology tools are not the primary answer to the challenges of rapid capability fielding. Contracting, available skills, organization, culture, budgeting, and other problems are tantamount and must be addressed. Nevertheless, the role of technology, if integrated into a composite overall solution, can have great impact on not only the delivery time, but also the quality, completeness and extensibility of the deployed solution.

A. General Observations about Rapid Fielding Programs

For a new rapid capability activity, a notional series of steps (some of which can be skipped or attenuated, depending on the specific effort) are as follows:

- The process is initiated with the identification and careful documentation of a need or a capability gap which should be addressed in order to improve capabilities.
- One or more proposed solutions are then evaluated, resulting in a concept for a product or process that can adequately address the need.
- This concept forms the basis for detailed design, which specifies exactly how the product or system will operate, how it will interact with users and other systems, what hardware and software components are required, etc.
- The design then feeds the development of a prototype as well as manufacturing considerations.
- The prototype is tested, with the results influencing the decision to conduct further design or proceed to production.
- Once an initial quantity is developed, the product or system is fielded and then must be appropriately supported and maintained.

This generalized cycle served as the framework for analyzing current rapid capability fielding programs to identify leverage points where tools could significantly improve the DoD's ability to rapidly field capabilities. Figure 2 depicts the generalized cycle and includes observations about each phase.

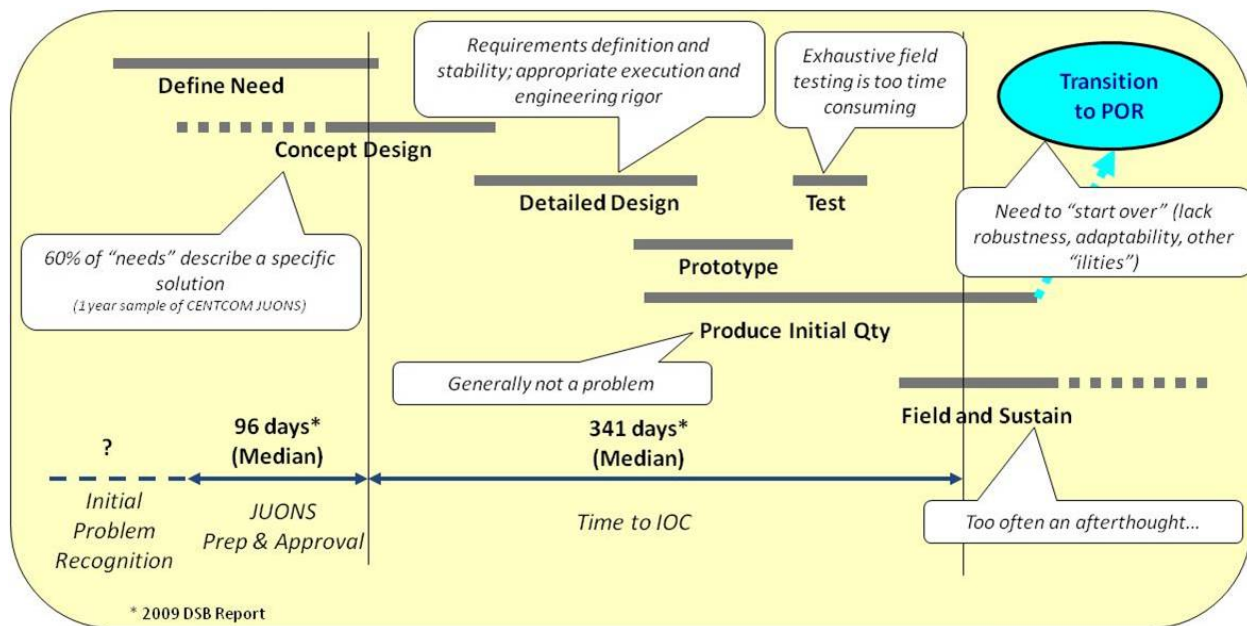


Figure 2: Generalized development cycle applied to DoD rapid capability fielding programs with observations.

The data included along the bottom of Figure 2 illustrates the median time to fulfill urgent requirements identified and validated as Joint Urgent Operational Needs (JUONs)⁵. In over 50% of the cases, the stated “needs” described a specific solution⁶. The implication in these cases is that the initial problem was recognized earlier and the solution definition begun well in advance of the formal JUONs document. The start date for the emergence of an urgent need is often not well defined, but concept design work begins as early as possible and does not wait for the paperwork. The median time from approval of the JUONs to initial operational capability was just under a year (341 days), and was skewed by the high proportion of non-developmental items. For solutions requiring development and integration, the median time from emergence of the need in the field to delivery of a solution is greater than a year.

Some rapid capability fielding programs result in solutions to a transient problem, and there is no need for a long sustainment period. In other cases, however, the need persists and the initial rapid solution must transition to a long term Program of Record (POR). While analysis of PORs was outside the scope of this study, the ability to efficiently transition a rapidly developed capability to a POR was considered. By definition, rapid capability development programs take short cuts in comparison to the deliberate acquisition process that addresses the full range of life cycle considerations. The ability to decrease or eliminate transition difficulties (e.g., expenditures of resources to “start over”) is therefore an important metric in assessing rapid capability fielding programs.

The balloons in Figure 2 represent observations identifying specific problem areas where the application of technology tools can make a significant impact. The first observation is that needs statements often describe specific solutions and not true stakeholder needs. This takes the level of conversation away from a required capability and instead focuses on the envisioned solution of a few stakeholder groups.

⁵ Defense Science Board, *Fulfillment of Urgent Operational Needs*, DSB Task Force Report. July 2009.

⁶ Analysis of one year’s sample of urgent needs requests from CENTCOM.

Often, these stakeholders provide sound operational perspective, but are unaware of either the other potential technological solutions or the longer-term impact of a specific solution (e.g., maintainability considerations for a pure commercial, off-the-shelf (COTS) product). This initial focus on solutions instead of needs reduces the opportunity to explore and provide more appropriate capabilities. If needs instead of solutions are discussed, developers who understand what is technologically feasible may be able to suggest better solutions. They may also be able to anticipate additional needs and provide better options for performance, usability, security, adaptability and other attributes.

The panel observed a tendency for rapid capability development programs to make implicit, rather than deliberate, explicit judgments on how much systems engineering process and discipline to apply. Most often, the rapid capability development programs opted to apply very little of the rigor and documentation requirements of the DoD 5000.2 process. This may save time in producing the initial units, and is entirely appropriate for many projects, but omitting steps and certain key documents in those cases where a complex material solution requires development can create development challenges and downstream issues with fielding and sustainment. The lack of documentation (either of the elements of the “real” need or of the data captured during development) also makes it difficult to upgrade the capability or to transition to a POR. This often forces PORs to restart the development process after transition.

While completing the full regime of traditional operational testing is usually too time consuming for rapid capability fielding programs, sufficient lab and field testing must be performed to ensure that the solution is safe and that the capabilities and limitations are understood well enough to use the item in military operations. This includes assessing compatibility within the larger operational environment (e.g., the need to ensure that the introduction of electronic jammers does not interfere with other commercial, government, or military electronic capabilities such as communication systems). In many cases, DoD lacks the tools to help reduce the number of field test iterations and thereby strike a balance between adequate testing and saving time.

Sustainment is rarely considered as a part of rapid capability development programs, resulting in deployed capabilities that may be abandoned because they cannot be repaired, short life-spans because training is focused only on the one or more initial unit(s) receiving the capability, or downstream issues when the capability requires further upgrades⁷. Ignoring sustainability issues up front may initially save time; however, the long-term impacts can be extremely costly and time consuming. Experience and judgment are needed to achieve the right balance between investing time to address sustainment and taking shortcuts to provide a capability in a timely manner.

Based on discussions with SMEs, the availability of manufacturing tools and technology (those used to improve the manufacturability and producibility of a product) does not seem to be a major limitation in the rapid production of small quantities of material solutions. There may however be profound challenges in cases where large quantities need to be produced quickly. Regardless of quantity, the effects of manufacturing tools and technology must be measured against the total time to deliver,

⁷ Discussions with the MRAP program and the OSD Rapid Fielding Office representatives.

including parts sourcing, supply chain operations, and quality control, rather than just increasing the speed of factory-floor processes.

B. Leverage Points in Rapid Capability Fielding Programs

The greatest opportunities for impacting the execution of rapid capability programs reside in the “front end” of the life cycle, specifically in the period between the emergence of a need and the beginning of the detailed design of a chosen solution. Technologies improving the need, definition, and concept development phases have the greatest potential return on investment and should be the priority for the development and implementation of technology tools. Technologies supporting an improved understanding of operational needs will increase the likelihood of the solution addressing the real underlying needs, versus fleeting symptoms. They will also help ensure adoption of the solution by the user community. In concept development, technologies supporting the rapid development, “red teaming”, and trade-off of solutions—to include non-material aspects such as CONOPS and TTPs—will ensure that the best possible solution is chosen from a properly balanced technical and operational perspective. This is best done by simultaneously immersing users and developers in an appropriate concept development environment.

Incorporating technology tools into other phases of the development cycle will also improve DoD’s capabilities. While the return on investment may not be as great as it is in the front end, technology tools can improve the overall development process if they are used in the following areas:

- Improved detailed design. Tools that reduce the number of iterations required in detailed design (e.g. accurate, high-fidelity physics-based simulations) will shorten the timeline. Increased automation, to include improved interoperability between tools, will reduce workload and error rates in translations. This will increase the efficiency of the detailed design phase, thereby shortening the overall timeline.
- Increased use of prototypes. Tools that enable more rapid development and earlier assessment of prototypes—both physical mockups and functional prototypes—will shorten the timeline by enabling earlier assessments by stakeholders such as the user and manufacturing communities. The increased use of prototypes benefits both the concept development and detailed design phases.
- Improved testing. Tools that enable or increase automated testing will shorten the time required for verification and validation of a product, operational assessment and enable broader-based testing prior to fielding. These tools may also include both methodologies to trade test-space and time, and the use of M&S tools earlier in the development process – in lieu of formal testing after prototype development.
- Improved manufacturing. The greatest benefit of new manufacturing tools (including manufacturing simulation, design for fabrication and assembly technologies, and reduced tooling techniques) and technologies may be in enabling rapid prototyping early in the program. In the longer term, advances in a small lot production of custom items can reduce the need for

heroic efforts and the risk of burnout in an environment that includes a steady diet of crash projects.

C. Impact of the Spectrum of Rapid Capability Fielding Challenges

The challenges encountered in rapid capability fielding programs require a collection of tools (a “toolbox”) that enable well-trained and dedicated people to rapidly develop appropriate solutions. This “toolbox” requirement arises from the diverse range of systems required to meet operational needs. Rapid solutions include, but are not limited to, software (e.g., decision support and analysis), electronic systems (e.g., jammers), air/land/sea vehicles, weapons, and chemical, biological, radiological, nuclear, and high-yield explosives (CBRNE) defense and forensics systems (e.g., rapid identification capabilities). Each of these domains has unique design, test, and manufacturing challenges. For example, automated tools for software engineering differ from the computer-aided design/computer-aided engineering (CAD/CAE) tools used in hardware development. CAD/CAE tools for electronics design differ from those used for aerospace structures. Software design tools focus on process logic, with the solution often requiring extensive testing for accreditation. Electronic systems are designed using electrical engineering tools for circuit design, to include logic models, and physics models to understand electromagnetic interference, shielding requirements, etc. Structural design tools focus on physical dimensions, physics, and material strength, with solutions that also require testing prior to fielding, although in both software and hardware cases there are tools that can reduce the need for testing and accelerate test time. Biological detection systems, including forensic DNA analysis, require wet chemistry and are designed with tools incorporating fluid mechanics and biochemistry. This diversity of domain challenges requires an engineering environment that can accommodate a diversity of tools, manage data and tool interoperability, and improve integration at the system level.

D. Engineering

1. Engineering and Execution Strategy

The degree of engineering discipline in rapid capability fielding projects is mixed. The formality of the system engineering process ranges from none to “5000-lite”. While traditional development programs utilize the DoD 5000 tailoring guidance to determine which tools and processes should be applied (critical reviews, systems engineering plan, test and evaluation master plan, etc.), an analogous method does not exist to support rapid capability fielding programs.

Using existing engineering processes as a starting point is not the best approach for rapid capability fielding programs. To be successful, rapid capability development programs must have the flexibility to appropriately trade comprehensiveness for time (e.g., agility in solution development). Often the DoD 5000 guidance on SE is implemented in a way that becomes focused on *process* at the expense of a focus on *outcome*. A manifestation of this tendency is the focus on documentation vice creativity. While documentation is a necessary component of any development program, creativity is likely to be more critical to the success of a rapid capability fielding program than in a traditional, less time-constrained program. There is high leverage in tools that aid in the capture of requirements,

specifications, and engineering design data, and that automate the generation of highly usable documents without slowing down the process.

Industry provides examples of tailored engineering processes. For example, some corporations have developed matrices relating work products to project types. Work products are then categorized as *not applicable*, *recommended*, *optional*, or *mandatory* for each type of project. Another approach industry utilizes is to form an expert team that meets during project kick-off. The team assesses the risk associated with the project and develops a list of project-specific engineering processes that balance risk management and resources (to include available time).

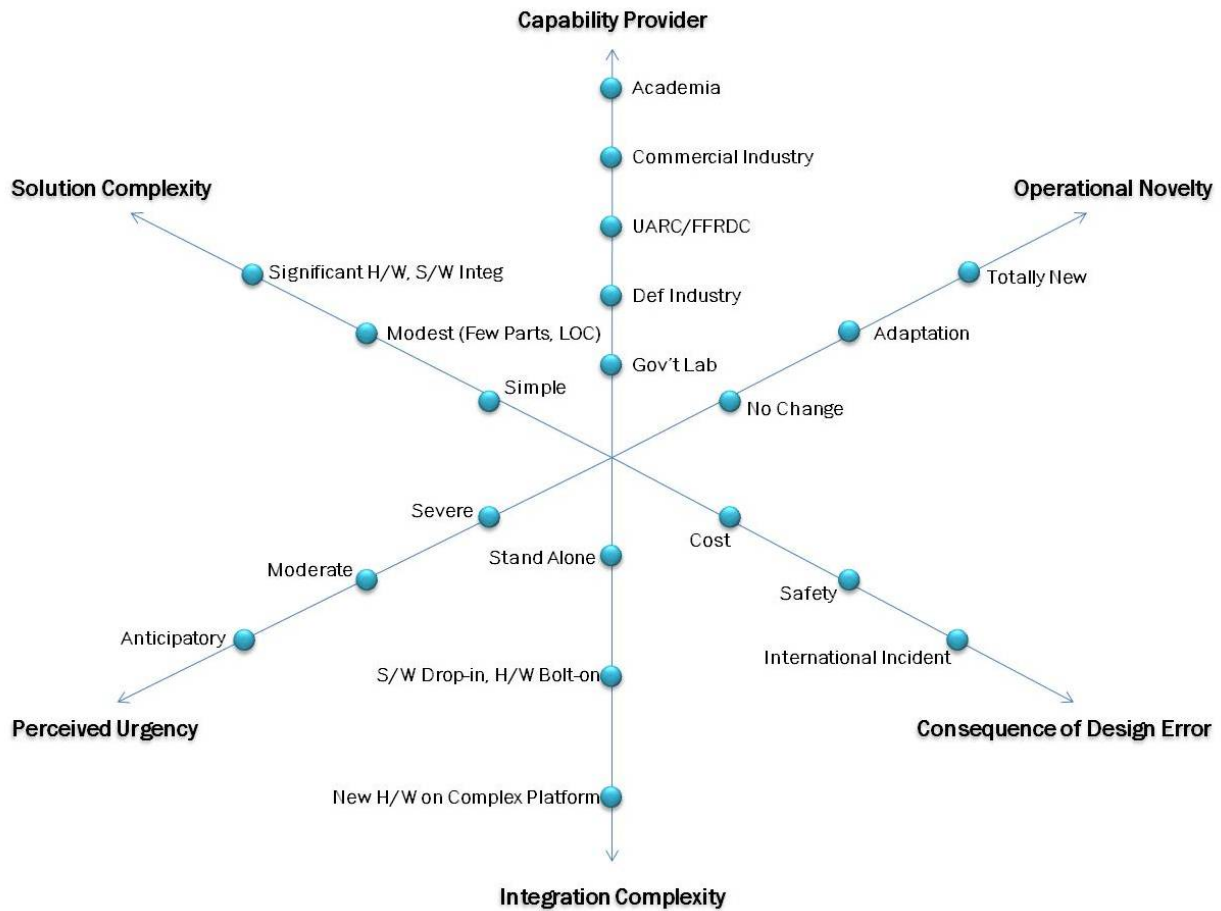


Figure 3: Dimensions of risk impacting rapid capability programs⁸.

Although industry processes are instructive, if adopted, they must be tailored to address the specific dimensions of risk inherent to rapid fielding projects and are highlighted in Figure 3. The risk dimensions must be assessed very early in a rapid capability project in order to obtain a comprehensive snapshot of risk and impose only the necessary execution and engineering rigor. The dimensions shown in Figure 3 include the following:

⁸ Adapted from presentation given by Mr. Ben Riley to the study panel on 02 September 2009.

- Capability provider – There are a large range of solution providers that may be involved in developing rapidly-fielded capabilities. This range includes government laboratories, the defense industry, university-affiliated research centers (UARCs), FFRDCs, commercial industry, and academia. Each provider represents a different level of risk through their understanding of the problem and in the team’s ability to execute and deliver a product suitable for fielding.
- Operational novelty – Rapid fielding programs must address varying degrees of operational novelty and complexity. Novelty ranges from solutions which require no changes in operational procedures, to solutions requiring that new CONOPS and TTPs be developed from the ground up. The degree of operational novelty impacts the probability of acceptance by the users in the field and may demand a great deal of inculturation and interaction with many communities to reduce the risk of the solution not being adopted.
- Consequences of design error – These may range from cost (e.g., increased unit costs to repair an error in design) to the possibility that the design error is the source, or contributes significantly to an international incident (e.g., targeting error creating collateral damage). The higher the consequence of a design error, the more rigor and oversight that must be applied.
- Integration complexity – This complexity ranges from stand alone solutions (low risk) to solutions that result in new hardware / software subsystems being integrated into a complex system platform (high risk).
- Perceived urgency – The perceived urgency of meeting a requirement influences the risk by impacting the senior leadership support for the project. Needs that are perceived as severe will likely have greater support and therefore more resources available to them than a project focused on meeting an anticipated need.
- Solution complexity – The complexity of the solution directly impacts the program risks. Programs with simple solutions involve less risk than those requiring significant hardware and software integration. This risk differs from *integration complexity*, which represents the risk associated with integrating the solution with *outside* systems—whereas solution complexity is *inwardly* focused.

2. Crosscutting Engineering Challenges

Several cross-cutting challenges are evident in the current engineering toolset:

- The front end of the development process—development of the concept and CONOPS—does not adequately exploit tools leveraging advances in visual modeling, virtual environments and rapid prototyping. This limits creativity and solution completeness during this critical phase and further encourages the trend to lock onto the first feasible solution identified and not fully explore the solution space.
- There is a lack of tools, metrics and process to support rapid assessment of non-functional, system-wide requirements (the so-called “-ilities,” such as reliability, maintainability, etc.). This

is especially true during the concept and CONOPS development phases, where such information would be highly valuable in selecting solution concepts.

- The time required to accredit software and security systems can be significant and limits the ability to rapidly field capabilities. While this was not a focus area, the panel believes that the exploration of accreditation technology tools (in addition to any necessary process reforms) may be beneficial.
- Rapidly-fielded capabilities often must integrate with legacy systems. There is a significant lack of reverse engineering tools available to meet this need. This results in a laborious “manual” process and also increased test time to understand the details of the legacy system in order to create appropriate interfaces with new capabilities.

3. Engineering Tool Trends

There are significant positive trends in engineering tools that, if adopted, will improve the rapid fielding of capabilities. One specific trend is the increasing commercial use of model-based engineering (MBE).

In software engineering, for example, MBE takes the form of model-driven software development (MDSD). The current state-of-the-art is executable unified modeling language (UML) with auto-code generation and metadata interpretation. The state of the art is centered on the domains of enterprise integration and application development. Further advances in MDSD require the development of tools for the creation of executable use cases / scenarios and for model-driven integration of simulation incorporating automated configuration and change management⁹. Development of these tools will enable the creation of an expanded set of model-driven capabilities to include the following:

- Executable models spanning requirements development through code generation.
- Model-driven testing with completeness and consistency checking.
- Automated configuration management and change control.
- Model-driven discovery and integration of composable services.

Although MDSD is an emerging field, several vendors have demonstrated significant improvements in developing software through the use of MDSD. They include the following:

- UNIQUESOFT has demonstrated examples of greater than 50% improvement in elapsed time for the development of software systems for large scale customers, by using its Unique Soft Automation Development Environment¹⁰. This product focuses on the domain of complex embedded systems and utilizes an approach that allocates the majority of the development effort toward the generation of correct requirements. Built-in rules for completeness and correctness of requirements allow the actual code to be generated with little to no human

⁹ Communication with Yngvar Tronstad.

¹⁰ Presentation to the panel by Dr. Terry Heng on 19 October 2009.

intervention. In addition, the resulting code occupies less space than a comparable human coded system and the code runs considerably faster than that produced by direct human effort.

- Cogility Software has also demonstrated a similar 50% improvement in the speed of development, deployment, and maintenance as a result of built in completeness and consistency-checking with its Cogility Studio. The domain focus for Cogility Software is model driven architecture (MDA) solutions for enterprise-scale crosscutting processes, data integration, web services integration, and complex event processing.
- IBM is developing MDA offerings that are based on its capability-diversified software acquisitions including Rational, Telelogic (Rhapsody, System Architect, Doors, etc.), Cognos, and Popkins System Analyst. The IBM approach is based on tailorable templates derived from best practices.

The Object Management Group (OMG) is incorporating emerging standards for W3C, SysML, RDF, OWL, and BPMN into their MDA standard. This formalization will generate a significant number of new vendor offerings that support MDSD.

In hardware design, the most mature example of MBE is in the design of integrated circuits (ICs). Prior to the 1970s, individuals “hand designed” ICs with the designer laying out each individual transistor and connection on the chip. The increasing complexity of circuit design required a new approach to enable the placement of thousands (and now millions) of circuit elements, and also to enable manufacturers to meet schedules for next generation products. A new approach that traded design optimality for speed during the design phase was adopted. That approach relied on the following:

- Design rules and design libraries that sacrifice localized performance optimality for design speed and global chip design optimization.
- Functional design abstractions, languages, and tools that enable the development and implementation of standards for interoperability of the tools used in design and manufacturing.
- Simulation models that validated logic and timing.
- Model-driven process control for high quality production.

The implementation of these elements, combined with roadmaps synchronizing advances in electronic component feature size, the use of increasingly higher levels of abstraction, and the implementation of interoperability standards for tools for design and manufacturing continues to enable the realization of Moore’s Law¹¹.

The benefits of MBE make it an appealing concept for rapid hardware development of systems beyond electronics. One benefit would be the reduction in translation errors caused by designers, engineers, and manufacturers as they manually translate information from one system to another. The use of

¹¹ Sangiovanni-Vincentelli, A. *Complexity in Microsystems*. Presentation from the DARPA March 2009 MTO Symposium. 25 January 2010. <http://www.mtosymposium.org/Proceedings/3_3_Sangiovanni-Vincentelli.pdf>

hierarchical abstraction and comprehensive model-based (versus documentation) capture of system designs would also support easier modification of systems. This would further reduce the time required to develop, integrate, and field capabilities, especially capabilities requiring significant integration with complex platforms and systems. An additional benefit of MBE is that it supports the rapid reconfiguration or updating of platform systems¹². There are, however, significant gaps in hardware design tools that would need to be addressed.

A new Defense Advanced Research Projects Agency (DARPA) program, called META, has the goal of extending MBE techniques to the system level for complex DoD systems, and demonstrating the benefits in reducing development time. The notional aircraft example (shown in Figure 4) contrasts today's separate design flows for power, actuation, lubrication, thermal management, and control/communications systems against the future process that META envisions. Design abstractions, component and process libraries, and other concepts similar to those used in the IC domain are the development targets of the META program.

¹² Siddiqi A., de Weck O.L., "Modeling Methods and Conceptual Design Principles for Reconfigurable Systems", *Journal of Mechanical Design*, 139, 101102, October 2008.

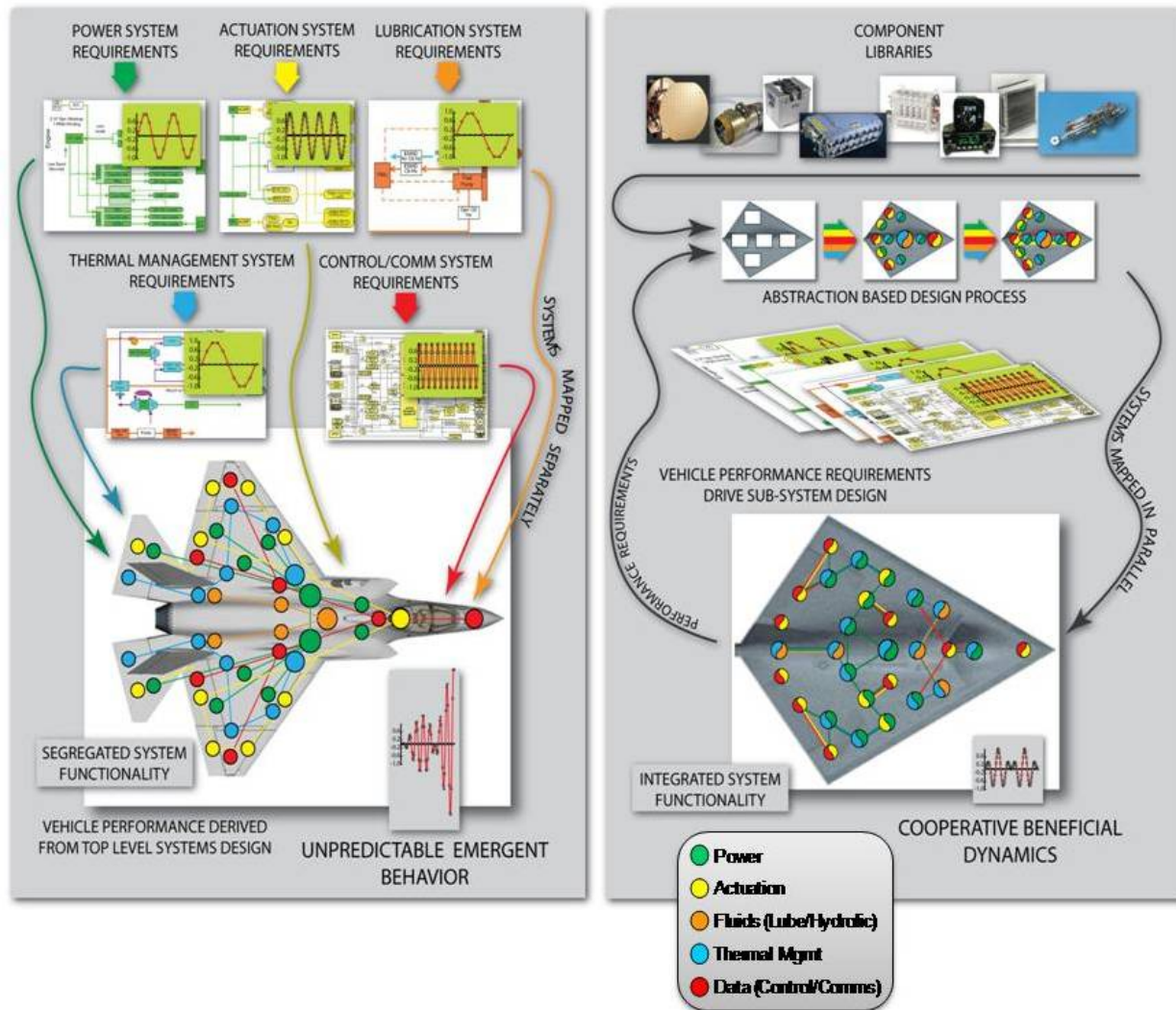


Figure 4: Example of model-based design flow employing hierarchical abstraction and auto-design techniques that could be applied to aircraft systems¹³.

Commercial industry is using MBE with increasing frequency and it will likely become standard practice. The benefits of MBE are compelling, however many technology gaps remain. For example, tools are available to support the auto-generation of software code; however, most tools do not automate the effective translation of use cases into the executable models. A hardware example is the lack of tools to translate abstract high-level system models to CAD / computer-aided manufacturing (CAM) (the exception is in microelectronics design and manufacturing). There is also an increasing use of virtual environments and digital threads from the design through manufacturing phases. These levels of automation may help to improve the speed at which systems engineering and design occurs, improving the ability to field capabilities rapidly.

¹³ Adapted from presentation given by Paul Eremenko to the study panel on 29 September 2009.

A roadmap capturing the current tool status and supporting the tailoring and adoption of MBE tools is required. While government programs like META will advance the state of the art, and commercial endeavors like those of Uniquesoft, Cogility and IBM will improve the state of practice, the sheer number of individual engineering tools and their current limitations and their interoperability needs argues for a MBE tool roadmap.

E. Modeling and Simulation

The M&S community is vast, with a good deal of excellent work occurring in pockets. For example, the Computational Research and Engineering Research Tools and Environments (CREATE) program has invested significant resources to create computational engineering tools to support the design of air vehicles (aerodynamics, air frame, propulsion, control, and early rapid design), ships (early-stage design, shock damage, and hydrodynamics performance), and radio frequency (RF) antennas (RF antenna performance and integration with platforms).

While the acquisition community has focused on physics-based models and constructive simulations of systems effectiveness, the DoD training community has taken the leadership role in adopting emerging M&S tools in the areas of games and virtual, mixed, and augmented reality (Appendix I). These tools, if adopted by the acquisition community, have the potential to significantly impact rapid fielding capability.

Among the M&S capabilities leveraged by the training community is the ability to rapidly create games in virtual environments. For example, DARPA's RealWorld allows the user to create an operationally relevant "game" representing an actual geophysical location in no more than four steps. The resulting virtual environments are extremely realistic (Figure 5) and have been extensively used for training, mission planning, and rehearsals.

Marine Corps MOUT Site – The RealWorld Version

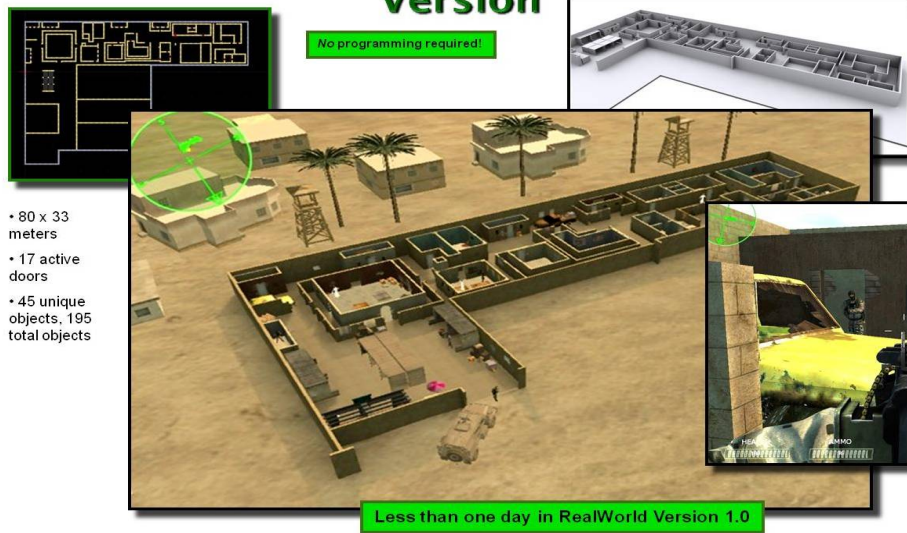


Figure 5: Example of RealWorld output created in less than one day¹⁴.

Virtual gaming tools can be created to support a variety of operational environments such as the ground operations represented in Figure 5 or the UAV and underwater operations pictured in Figure 6.



Figure 6: Examples of RealWorld outputs supporting air and undersea operations¹⁵.

Virtual, augmented and mixed reality environments are more complex to develop and deliver than gaming environments. They have been successfully adopted and deployed by the training community with very positive results. The Future Immersive Training Environment (FITE) Joint Capability Technology Demonstration (JCTD) uses a wide variety of individually-worn virtual reality elements, facility-based mixed reality, and individually-augmented reality to support pre-deployment training. The

¹⁴ Adapted from presentation on RealWorld given by Dan Kaufman to the study panel on 19 October 2009.

¹⁵ Adapted from presentation on RealWorld given by Dan Kaufman to the study panel on 19 October 2009.

mixed and augmented reality components enable highly realistic representations of the actual operational environment, to include temperature, humidity, odors, haptic interaction and the use a full range of real combat equipment.

Physics-based simulation applied to engineering design can have substantive impacts on rapid capability fielding programs by reducing the number of test-build-test cycles required to converge on a workable solution. This approach has not only been used by the DoD in a wide variety of efforts, but also by commercial industry (e.g. Goodyear in designing tires)¹⁶. DoD application areas range from complex platform (e.g. aircraft, ships) design to weapons effectiveness and electromagnetic interference (EMI) modeling. Modern military operations are highly dependent on electronics and communication systems, which are vulnerable to EMI. The study schedule prohibited an in-depth examination of this area; however, a preliminary review indicates that a physics-based EMI modeling effort focused on supporting rapid capability fielding programs may be warranted. Finally, the panel observed that the development of physics-based models can be extremely expensive and time consuming. Although the potential impact of these technologies is great, the S&T community should embark on efforts to reduce the total cost and duration their development.

Another area where the application of M&S holds promise in not only reducing the time required to develop systems but also increasing the effectiveness of the capability, is in modeling human/cultural behavior. An effective model of human/cultural behavior would be extremely valuable in assessing the effectiveness of a specific solution, not only from the U.S. perspective, but from enemy, non-combatant, and other key viewpoints. Unfortunately, DoD's current ability to model this behavior is limited; but the integration of agent-based modeling concepts coupled to Monte Carlo simulations and real world calibration through the use of Massive Multi-player Online Games (MMOG) holds promise.

DoD has an extensive M&S community; however, visibility into the various organizations and their capabilities is limited. The study panel observed that the limited visibility is likely restricting the application of M&S capabilities to rapid capability fielding programs. In addition, this limited visibility increases the likelihood of interoperability issues among M&S capabilities developed in the department.

F. Manufacturing

The ability to manufacture modest quantities of a solution has usually not been the limiting factor in rapid capability fielding. However, many examples required "heroic" efforts. Two such examples are the Mine-Resistant Ambush Protected (MRAP) program and Warlock Blue (Appendix D). In both cases initial production met targets. However, this was only due to extraordinary efforts (e.g., working nights, weekends and holidays) to source parts and critical materials, manage supply chains, conduct manufacturing process planning, translate designs into numerical control code, operate production, assembly and quality control, ship items to the user, and support them in the field. These practices are feasible for short-term production runs and relatively small quantities (by commercial standards). Quick-reaction production capacity when large numbers are needed, however, may be an issue.

¹⁶ Post, D. "The Promise of Science-Based Computational Engineering." Computing in Science and Engineering (2009):2.

DoD laboratories have substantial in-house manufacturing capabilities distributed across many sites, both in the continental United States (CONUS) and outside of it (OCONUS). This capability is neither visible nor easily accessible to many rapid capability fielding programs. Additionally, while these laboratories have state-of-the-art capabilities, there does not appear to be a unified plan to ensure that these manufacturing capabilities are maintained and upgraded over time. Such a long-term coherent strategy, coupled with increased visibility, should provide the department with a valuable source of manufacturing capabilities to support the production of small quantities often required in a rapid capability fielding program.

Rapid prototyping is a critical function that is closely related to manufacturing, but differs in that the products do not necessarily make it to the field, and they support the entire rapid capability development life cycle. Prototypes include both physical mockups and functional or semi-functional prototypes. Physical mockups have physical characteristics similar to the envisioned solution (e.g., weight, size, location of control features, and shape) but usually have limited or no functionality. Functional prototypes are working (or at least working for key elements of the product or system) models that may have the same (or similar) physical characteristics as the envisioned solution.

Both physical mockups and functional prototypes are invaluable in assessing the effectiveness of possible solution concepts. The integration of physical prototypes with user-centered design tools and principles (Appendix E) is a critical step in producing a solution that is widely-accepted among warfighters. Both physical mockups and functional prototypes can also be incorporated into CONOPS development. This integration would enable the assessment of physical designs and functional characteristics against a range of CONOPS, informing the selection of the most effective solution within a defined set of CONOPS. Functional prototypes would also provide value in validating engineering concepts during the detailed design phase. The capability resident in DoD laboratories can generally produce the small numbers of prototypes required to support rapid capability fielding programs.

Rapid prototyping uses a wide variety of technologies. An example technology is additive manufacturing. The additive manufacturing community has developed a roadmap¹⁷ to improve the state of the art in the areas of (1) design, (2) process modeling and control, (3) materials, processes, and machines, (4) biomedical applications, and (5) energy and sustainability applications. Leveraging this and other industry roadmaps, where appropriate, would enable DoD to enhance their ability to develop and deploy rapid prototypes, and in some cases, small lot production.

When considering manufacturing in the context of rapid capability programs, there is a tendency to strictly focus on time-on-tool. While this may be appropriate for programs with extended manufacturing runs, a better metric for limited production runs is the total manufacturing time. This includes the time required to plan for the physical manufacturing run and to establish and manage a supply chain, which usually consumes considerably more time than the time-on-tool.

¹⁷ "Roadmap for Additive Manufacturing: Identifying the Future of Freeform Processing." 2009. 25 January 2010. <<http://www.wohlersassociates.com/roadmap2009.html>>

Table 1: Top level summary of the state of the art in model based manufacturing¹⁸.

	Innovation & Conception	Design & Engineering	Process & MFG	Sustainment & Provisioning
Current State	<ul style="list-style-type: none"> • Easy to use 3D drawing packages • Many electronic catalogs for reference • Visualization is the present cornerstone 	<ul style="list-style-type: none"> • Product lifecycle management (PLM) vendors acquiring and supporting product and process design and analysis toolsets 	<ul style="list-style-type: none"> • Good factory management models exist • Science based process models are available 	<ul style="list-style-type: none"> • Product model data (2D or 3D) for use in planning estimates for needs and logistics • Manual translation often required to apply model to sustainment activities
Problems	<ul style="list-style-type: none"> • Visualization by domains—limited awareness across domains • Visualization often not supported by analysis and trade tools • Focused on expensive environments • Concepts to designs not integrated 	<ul style="list-style-type: none"> • Must use single suite for best data transfer between functions • Transfer of data to analysis packages still labor intensive • Requires high skill level to use • Expensive to purchase and support • Knowledge components lacking 	<ul style="list-style-type: none"> • Product models do not support abstractions for process models • Design model and manufacturing models not compatible • PLM systems offer limited process modeling capability (mostly assembly) • PLM systems do not drive well to the shop floor 	<ul style="list-style-type: none"> • Different vendors use different modeling tools which do not share data • The valuable product and process data does not find its way to the product support system • 2-D legacy master product data limits 3-D utility

Manufacturing concepts and tools continue to improve, reducing the total manufacturing time (Table 1). This improvement is provided through a combination of manufacturing techniques that directly reduce time-on-tool, especially for low number or singular production runs, and tools that reduce the time to develop and manage supply chains. However, as indicated in Table 1, a variety of areas for improvement still remain.

G. User-Centered Design

User-Centered Design (UCD), also known as Human-Centered Design (HCD), as a discipline, focuses on developing an improved understanding of users' real needs. This improved understanding allows for better products and product design outcomes. UCD utilizes formal structured tools and methods to guide this improved understanding. Example tools include observational and conceptual frameworks such as POEMS (people, objects, environments, messages, and services) and contextual interviews. UCD leverages observations not only about how users utilize systems, but also how they modify them to better meet their needs. Interviews provide insights that better identify gaps in current systems and how those gaps might best be filled.

UCD has been used by a number of organizations, such as Boeing, OXO, the Chicago Transit Authority, Northwestern University, and Samsung. One example project that included significant use of UCD tools was the development of the Chicago Bus Rapid Transit (BRT). One of the key elements enabling success in this project was the use of low fidelity mock-ups to enable rapid user feedback and decision making. Another project leveraging UCD was the development of a device to

¹⁸ Adapted from presentation by Adele Ratcliff to the study panel on 03 September 2009.

measure hand hygiene compliance in a major hospital. In this case, simulating the environment allowed designers to identify and resolve problem areas prior to final design. In both cases, the application of UCD principals and techniques resulted in improved products.¹⁹

H. Summary of Findings

1. Significant opportunities exist to develop and deploy tool and process based technologies to strengthen the Department's ability to conduct rapid capability fielding. However, non-technical challenges (e.g. cultural, budgetary, and contracting) must be simultaneously addressed.
2. The greatest leverage is in the "front end" of the life cycle, especially in concept engineering. Technology tools can enable DoD to rapidly elucidate or anticipate needs, explore solutions, develop CONOPS, and derive requirements for materiel solutions. Virtual environments and rapid physical prototyping are specific linchpin technologies that appear to be ready for exploitation. User-centered design tools and processes require further development and integration, but also represent a significant opportunity space.
3. While the Services are developing and using tools to enhance rapid capability fielding (see Appendix J), opportunities exist to increase design, test, and production efficiencies. Examples include physics-based M&S to reduce testing, and model-based engineering and manufacturing approaches.

¹⁹ Presentation by Hugh Musick given to the study panel on 19 October 2009.

III. Tool-enabled Rapid Capability Development

Figure 7 illustrates the framework considered when applying technology tools to the rapid capability challenges. A two step process exists in the near term. Concept engineering is the “front end” of the capability development cycle and is followed by capability engineering. In this framework, *concept engineering* includes the need definition and concept design phases while *capability engineering* includes detailed design, prototyping, test, and limited quantity manufacturing. Inputs to concept engineering include stated and unstated needs, technology opportunities, and red teaming results (if done prior to concept engineering). In the near-term, concept engineering provides outputs, such as conceptual designs, CONOPS, TTPs, and prototypes to capability engineering. Over the long-term, advances in tools and other technologies will create opportunities to rapidly create capabilities through the use of a fully integrated one step process: concept-to-capability engineering (C2E).

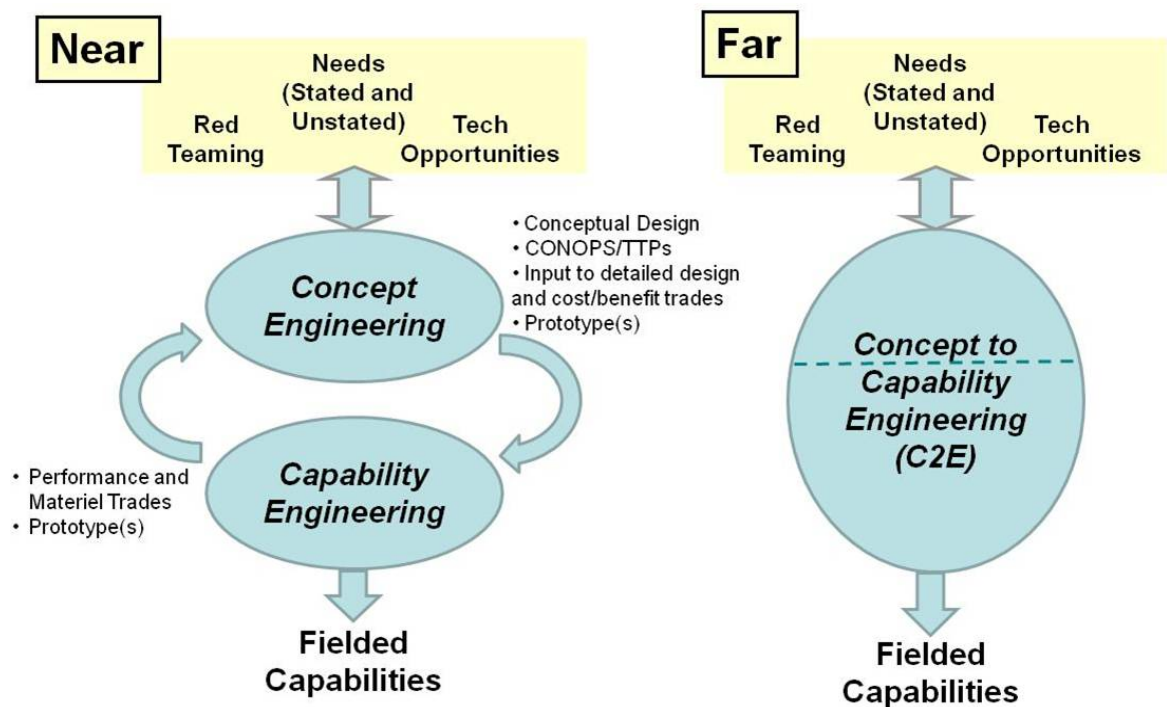


Figure 7: Near and far-term recommendations to improve rapid fielding capabilities.

A. Concept Engineering

Concept engineering is focused on problem-solving. It is designed to ensure that the system or product being designed provides the right capability to the warfighter at the right time. Therefore, concept engineering is “warfighter-centric,” requiring warfighter involvement regarding needs, gaps, and operational concepts.

Concept engineering, as envisioned by the study panel, is designed to accelerate the conceptual development and selection of the “best” solution to a current or anticipated need. “Best” means that the solution balances time to fielding with completeness, accounts for desired longevity of the solution, anticipates enemy response to the new capability, and is easily adopted by the warfighter. Using an iterative process between the concept design team and warfighters, supported by both virtual and real prototypes, is a key to success. Red teaming, through the use of experienced real-world users to “game” a proposed concept, is also desired if time and availability of personnel allow. The output of the concept engineering phase includes conceptual designs, a CONOPS that will define most common uses of the system, TTPs that will support the use cases for the system, and high-level physical or virtual prototypes that fit the *real* need based on user involvement in the process. All of these will then feed the development of detailed design and prototyping.

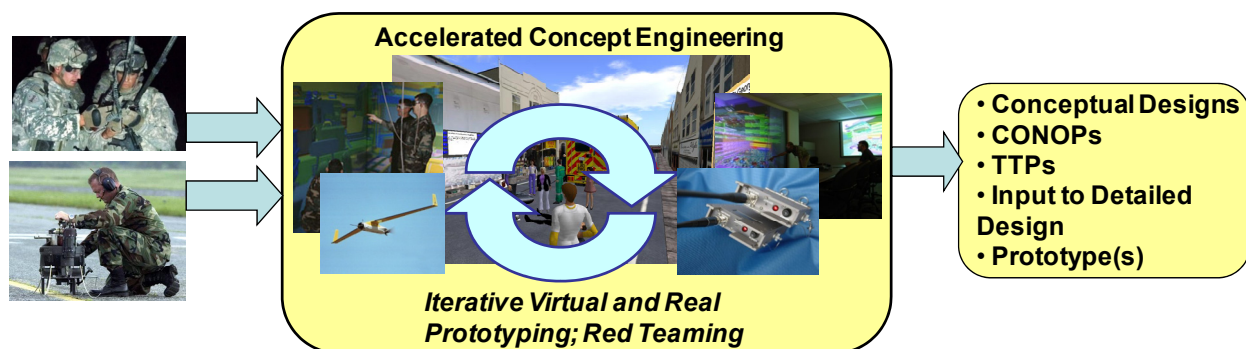


Figure 8. Graphical depiction of the Concept Engineering process.

Current operational environments consistently favor speed over fidelity. This does not mean that an ineffective system should be developed; instead, it means that a product representing a 75% solution that can be fielded in six months may be more valuable to the warfighter than a 95% solution that will be fielded in five years. There is a trade-off between completeness of a solution and timeliness. As rapid capability fielding improves, the ability to deliver more complete solutions in a timely fashion will increase. Concept engineering will facilitate this by bringing forward user input, exploring options more rapidly with both users and developers, and developing valuable insights from prototypes early in the development cycle. Furthermore, through the use of virtual environments, the critical interactions with users can, in many cases, be accomplished remotely, greatly increasing speed and access to diverse user perspectives.

It is recognized that all of the capabilities one might want to exploit in concept engineering may not be readily available at a given location. For instance, access to real range resources or high-fidelity simulations may be required to answer certain fundamental questions. Therefore, the notion of concept engineering implicitly includes the networking to other DoD-wide resources to be tapped as needed on a case-by-case basis. These resources could include, but are not limited to, simulation exercises (e.g. SIMEX), physical exercises, and field experiments. Furthermore, although there are cross-cutting and foundational tools that support concept engineering, domain specific challenges dictate the need for a wide range of domain specific environments that leverage a common toolset and best practices.

1. Concept Engineering Tools

Virtual environments, user-centered design, and rapidly developed prototypes are central to the improvement of concept engineering and are important components of a “toolbox” used in rapid capability fielding. The capabilities that are currently available in all three domain areas are sufficient to yield immediate improvements. Further technological developments in these areas will continue to enhance concept engineering capabilities and also better enable the integration of concept and capability engineering.

Gaming and Virtual Environments. Simulation tools should be used to create persistent virtual environments to better understand operational needs, rapidly assess solution concepts, and red team results. The environment should include not only gaming technologies but also, where needed and practical, the full range of virtual, mixed, and augmented reality components. There are many benefits to the use of virtual environments during the early phases of a development program. One such advantage is that modern tools enable the rapid creation of representative scenarios that can be used to explore solution concepts and their CONOPS simultaneously. The introduction of CONOPS, to include TTPs, as a variable early in the development cycle will enhance the overall process. Software tools can also be used to extract data from the simulation to form the basis for documented CONOPS and TTPs. The use of virtual environments also allows for remote users—perhaps even those users that submitted the initial needs statement—to directly participate in solution development and for users to provide real-time feedback. Additionally, the same virtual environments used to support both need identification and concept development can be used to bootstrap virtual training capabilities to accompany the fielded solutions.

While significant advances have been made in the rapid creation of gaming and virtual environments, additional work remains to be done. Existing projects, such as RealWorld and FITE, currently focus their efforts on supporting the training and mission rehearsal community. Their efforts should be expanded to include concept engineering support. The panel explored RealWorld as an exemplar of cutting edge gaming technology and assessed its capabilities and limitations in supporting concept engineering. Among the technical advances required for gaming technologies to better provide this support are the following:

- Development of a behavioral interface standard to support “plug and play” of artificial intelligence models.
- Further development and implementation of agent-based models and Monte Carlo simulation capabilities for virtual environments.
- Improved interfaces with Matlab and other engineering tools. The integration of Matlab and other engineering tools would enable more rapid and realistic assessment of solution concepts.
- Improved data logging, focusing on the auto-generation of CONOPS and TTPs. Video capture capability should be included as a component in data logging to assist in the refinement of the needs statements.

- Development of a virtual environment roadmap specifically focused on supporting concept engineering and the front end of the development life cycle in general.

User-centered design. User-centered design (Appendix F), sometimes also referred to by the more inclusive terminology, human-centered design (HCD), enables improved product designs through the use of a disciplined engineering process and tools designed to capture and account for true user needs. To maximize the usability of rapid fielding solutions, DoD should leverage user-centered design by taking the following actions:

- Create routine, structured user-centered feedback, especially from theater based warfighters. This feedback informs product designers and enables the development and evolution of improved designs that meet warfighter needs. The challenge, of course, is to gather this feedback without adding additional burden to the warfighter. There may be approaches that leverage existing personnel and resources already in theater. Such approaches might include building upon the DARPA TIGR (Tactical Ground Reporting) system and/or leveraging forward-deployed science and technology (S&T) personnel (with appropriate training) to participate in, or lead, the process.
- Explore the tools and techniques that are widely available in the design community. Examples include POEMS (People, Objects, Environment, Messages, Services), method cards, etc. Employ those that are deemed to add value.
- Update and enhance selected tools to insure that they meet DoD needs and integrate them both with one another and with appropriate engineering modeling tools.
- Employ a strategy of systematically anticipating user-centered design factors (proactive vice reactive).

Rapid prototyping. The rapid prototyping of physical mockups and functional units in concept engineering will inform CONOPS development, user interfaces, logistics, and maintenance driven design concerns very early in the life cycle. When combined with virtual prototyping, virtual environments, and user-centered design tools, it provides a powerful capability for more rapidly and accurately assessing concepts for real-world applications.

DoD has a vast array of rapid prototyping capabilities distributed across the country and at OCONUS locations. These distributed assets are often not visible to the individual rapid capability fielding project manager, and may therefore be underutilized. Such capabilities should be made more visible to individual development programs. Additionally, actions should be taken to ensure that these laboratories maintain cutting-edge capabilities.

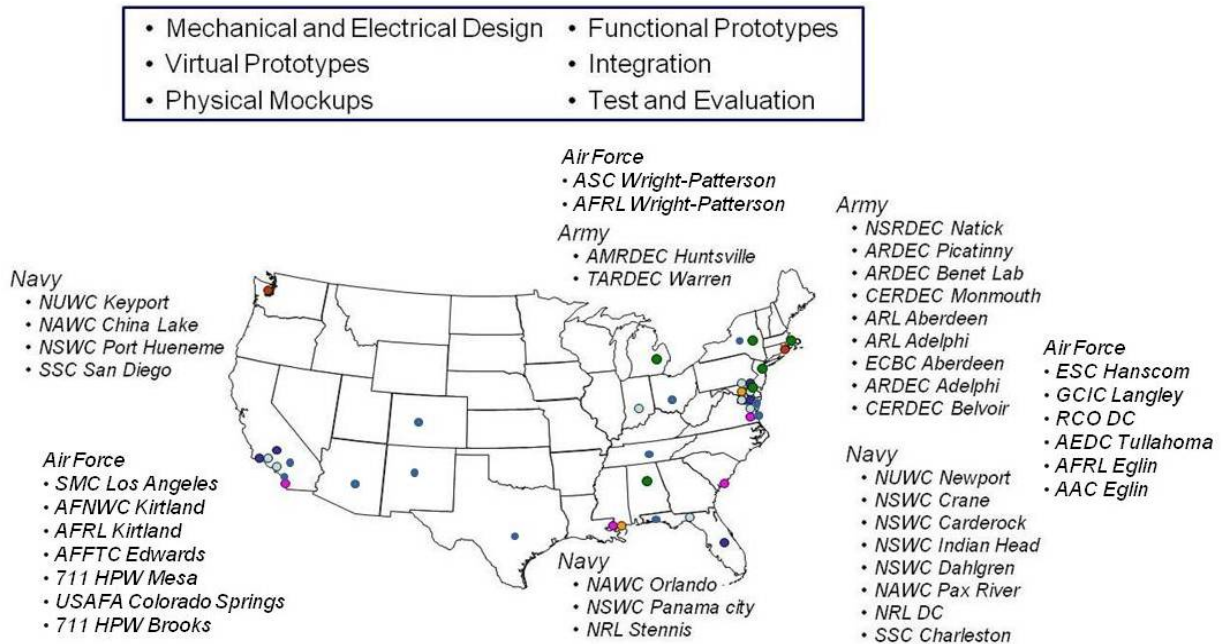


Figure 9: Representative locations of DoD facilities with rapid prototyping capabilities

2. Concept Engineering Recommendations

Recommendation: Establish a DDR&E-sponsored Concept Engineering Center (CEC)

DDR&E should select an initial domain and sponsor Concept Engineering Center (CEC) to support that domain. This CEC would immediately incorporate virtual environments, user-centered design, and rapid prototyping tools to establish a “proving grounds” for concept engineering tools and best practices for the domain of interest. To achieve this goal, the following actions should be taken:

Select a problem domain of interest. To aid in that selection, the panel suggests several possible pilot projects in this report. The selected domain should (1) represent real world problems, to include emergent problems, (2) be sufficiently broad in scope and time to warrant the creation of a persistent virtual environment, and (3) be of substantial interest to Combatant Commanders (COCOMs).

Invite the Services to designate CEC’s focusing on domains of their interest. The DDR&E-sponsored Concept Engineering Center (CEC) would work with Service designated CEC’s and serve as the nexus for the development of strategy and recommended techniques, tools, and methods within the DoD. The DDR&E-sponsored CEC would provide guidance and protocols for concept engineering; however, it would not be the venue where *all* concept engineering efforts occur.

A first-generation CEC can be immediately created with state-of-the-art tools. This CEC would immediately fill the role of a “proving ground” for emerging tools and best practices. The CEC should also establish, maintain, and provide links between the DoD, industry, and appropriate academic and independent research institution resources for concept engineering.

The CEC's should initially focus on two or three pilot programs within their domain areas. The pilot programs should be selected to the full suite of concept engineering tools and processes (virtual, prototyping, user-centered design, red teaming).

A strategy to staff, train, proliferate, and exploit concept engineering across DoD should be developed and implemented. This strategy should account for projects that are executed within DoD or by performers outside of the department. This will require engagement with industry, academia, and FFRDCs to fully proliferate concept engineering.

Recommendation: Develop a Strategic R&D Investment Roadmap for Concept Engineering Tools

A strategic R&D investment roadmap should be developed that focuses investments on gaming, virtual environments, rapid prototyping, and user-centered design tools to specifically enhance concept engineering capability. In all of these cases, rapid capability projects require technical enhancements that may not otherwise be recognized by other communities. Creating a roadmap viewed through a rapid fielding lens would be both instructive and instrumental in furthering the Department's rapid fielding capabilities.

Recommendation: Tailored SE and Execution Strategy for Rapid Fielding Programs

DoD should develop and implement a tailored engineering and execution strategy for rapid capability fielding programs. The strategy should provide the flexibility to tailor the approach for each individual rapid fielding program. The execution and system engineering strategy for each program should be determined by a small group (less than 10) of experienced personnel that meet early in a program to assess the multi-dimensional risk (discussed in section II.D.1) and select the appropriate level of rigor. They would also consciously impose the desired operational longevity on the project. In determining the overarching approach, they should assume a start point of no defined formal processes and then select the minimal set of processes, to include formal deliverables, to mitigate the risk. In selecting the program-specific tailored engineering and execution strategy, the panel may utilize a hybrid of "a la carte" and "packaged" strategies. This may include review gates, personnel requirements, formal deliverables, etc.

After projects are completed, the usefulness of the tailored strategy in mitigating risk should be assessed. These assessments should be used to further develop "packaged" strategies based on real-world evidence of utility. The development of "packaged" strategies will then inform broader strategy development and reduce the requirement for utilizing the small group review.

B. Capability Engineering

Capability engineering is the process of moving an accepted concept into detailed design, prototyping, testing, production, and fielding. Capability engineering is not performed in a vacuum; there are often iterations between capability and concept engineering, as lessons learned in detailed design affect the overarching design concepts. In addition, capability engineering must account for the non-functional requirements of a system that might not have been fully addressed in concept engineering—the "-ilities" such as security, usability, sustainability, etc.

1. Capability Engineering Tools

Physics-based models, model-based engineering, and model-based manufacturing are central to the improvement of capability engineering. They are also important components of a “toolbox” used in rapid capability fielding. Investments in these areas will enhance the ability to perform capability engineering and, over the long-term, better enable the integration of concept and capability engineering to realize C2E.

The use of physics-based models minimizes the need for rework and also reduces the time required for test and evaluation. To make models manageable they are developed for specific domain areas such as antennas (electromagnetic propagation), aeronautics (fluid mechanics), and weapon systems (strength of materials, Newtonian motion, etc.). Widespread use of physics-based models requires the development of reusable models, interoperability standards, and, in some cases, an improved understanding of the physics. Finally, while the use of models will likely reduce test and evaluation time, significant investments in Verification, Validation and Accreditation (VV&A) are required.

Another tool set with the potential to significantly enhance capability engineering are design-for-X (DfX) tools, where X is a specific attribute such as sustainability, reuse, manufacturability, etc. (see Appendix G). Broader utilization of these tools will reduce the overall time to design and field capabilities.

In addition to the application of physics-based models and DfX, model-based engineering and model-based manufacturing techniques and tools may also be applied. This will enable the transition from a dependence on documentation to the utilization of executable models that may eventually bridge the gap between virtual environments and CAD programs. By improving and even automating the transition between concept and capability engineering, DoD can greatly enhance future system modification speed and efficiency. Automating the seam between concept engineering and capability engineering (i.e., C2E), although a far-term goal, will provide enormous benefits in terms of efficiency.

2. Capability Engineering Recommendations

Recommendation: Pilot of Model-Based Engineering and Manufacturing

DoD should pilot model-based engineering and manufacturing in a relevant rapid capability fielding product area (e.g. multi-purpose unmanned vehicle [UxV]) by demonstrating a modular, open-system design using hierarchical abstraction on a convincing scale. The primary metric of importance for rapid capability fielding is not necessarily the time to first unit, but the time required to modify the first unit for multi-purpose applications. It is here that model-based engineering and manufacturing is expected to make a substantive impact to rapidly getting new capabilities to the field.

Recommendation: Invest in Capability Engineering Tools and the Transition to C2E

DoD should invest in capability engineering tools by:

- Identifying and funding shortfalls in physics-based modeling for rapid capability fielding. One specific area with the potential for high payoff is electromagnetic models supporting rapid electronic system insertion.

- Identifying and funding technologies in the “seams” between concept engineering and capability engineering (e.g., virtual environment (VE) to CAD tools).

Recommendation: Make Concept and Capability Engineering a DDR&E Thrust Area

DoD should include Concept and Capability Engineering as a DDR&E Thrust Area for Program Objective Memorandum (POM) 2012 R&D planning. To support this, the department should do the following:

- Appoint a senior-level leader to work across DoD components and engage defense and commercial industry, and academia, in developing a technology investment roadmap.
- Prioritize investments that have transition paths to rapid response organizations.
- Sponsor further basic research in C2E through the DoD Systems Engineering UARC and other university research mechanisms.
- Establish C2E training and career development programs for DoD engineers.

Recommendation: Inventory DoD Laboratory Capabilities

The DoD should inventory the capability engineering capabilities currently residing in the laboratory system and make them more accessible to rapid capability development programs.

C. Potential Pilot Projects

To best develop and demonstrate the recommendations listed above, several pilot programs are recommended. These pilot programs will demonstrate the benefits of concept engineering and capability engineering tools and environments.

1. Forward Operating Base Protection

The first recommended pilot is in the critical area of combat outpost and forward operating base (FOB) protection. This pilot would create a persistent, accelerated FOB protection concept engineering environment that provides for closed-loop physical prototyping, virtual gaming, and user-centered observation. The development of this persistent concept engineering environment will exercise the capabilities of the recommended concept engineering center and capabilities that are resident in other DoD organizations and facilities. The physical component of the pilot would demonstrate the utility of mockups and functional prototypes in evaluating solutions to issues such as emplacement effectiveness, human factors, and performance in a wide range of operational scenarios. The virtual component would employ state-of-the-art gaming technology to demonstrate rapid virtual FOB construction and scenario generation. The virtual FOBs and scenarios would be used to increase the developers understanding of needs, and also to develop and assess a wide range of capability solutions, to include CONOPS. Where possible the virtual component and physical components should be linked to provide improved feedback on proposed solutions. Additionally, this combination of virtual and physical components can be used to inform engineering tradeoffs, such as sensor technology requirements vice CONOPS.



Figure 10: Examples of forward bases. Clockwise from upper left: combat outpost, fire base, forward operating base, and patrol base.

The FOB concept engineering environment would also support red team evaluations. Through red team evaluations, one may be able to anticipate future needs and provide capabilities in advance of the requirement. Issues such as threats and sensor placement could be simulated using human controlled red/blue forces and/or artificial intelligence (AI) behaviors. The gaming technology could also be used for CONUS and OCONUS testing, training, and mission rehearsal support. It would also be possible to push the “game” to users in theater.

Much of the needed technology is available, but development is needed for representations of specific materiel options (e.g. sensors, displays) and some red weapons (e.g. mortars). This is development that could be done very quickly—in weeks, not months or years. The outputs of this pilot would be laydown plans for specific FOBs, CONOPS/TTPs, rapid materiel solutions that are robust and sustainable, and identification of capability gaps that can inform research, development, testing, and evaluation (RDT&E) plans and roadmaps.

2. Other Recommended Pilots

In addition to the FOB pilot, the following domain areas are also offered as pilots:

- **Intelligence, Surveillance and Reconnaissance (ISR).** This pilot would create a persistent ISR environment with physical and virtual elements used to explore requirements for automated exploitation and CONOPS tradeoffs (e.g., track duration and association). An example goal would be to explore how to spend the next dollar on capabilities within the ISR system of systems (e.g. whether on Ground Moving Target Indicators (GMTI), full-motion video, sensor planning or other capabilities).
- **Multi-purpose, adaptable UAV.** The primary objective of this pilot would be to demonstrate the power of model based engineering to support a design that maximizes rapid mission adaptation. As with the other recommended pilots, it would build and maintain a persistent virtual environment. This environment would be used to explore CONOPS associated with various missions and payloads. Instead of speed to produce the basic platform, the key metric

would be speed of adaptation. This pilot would also demonstrate the utility of physics-based modeling to reduce test time and ensure electromagnetic compatibility.

- **Maritime biometrics and media collection.** This pilot would use a mixed virtual and physical environment to evaluate concepts and CONOPS for ship boarding and data collection scenarios. The ability to rapidly develop both mockup and functional prototypes is a key component in this pilot. The prototypes, combined with the virtual environment, would be used to explore and assess the physical configuration options available when combining functions of media collection and biometrics collection.
- **Swarm UxVs.** Swarming UxVs have potential multi-mission utility for applications such as ISR or force protection. This pilot would develop a virtual environment to explore the operational utility of a variety of TTPs such as swarm tactics (to include swarm-on-swarm interactions) and technologies (i.e. vehicle and sensor capabilities). It would also be used to develop and evaluate counter swarm tactics for force protection.

Conclusions

Department of Defense programs that rapidly field operational capabilities can benefit from the development and implementation of technology tools in selected areas. The most immediate opportunity is the use of tools to improve the effectiveness and efficiency of the “front end” of the development cycle (“concept engineering”). The panel recommends that the Department vigorously implement concept engineering capabilities that exploit the simultaneous use of emerging tools in gaming, virtual environments, rapid prototyping, and user-centered design. These tools can be used to create persistent concept engineering environments that would rapidly assess various concepts while simultaneously developing CONOPS/TTPs. This environment would enable users and developers to work hand-in-hand from the very outset of a project, ensuring the best possible solution to the properly defined problem is delivered.

The application of model based engineering to the detailed design and manufacturing phases can reduce translation requirements and errors—and therefore time and resource requirements—as well as reduce the total time to manufacture. Moreover, once systems are developed using model-based approaches, it would be far easier and faster to modify them to rapidly respond to an urgent need. The Department should leverage the commercial progress in this field and begin to pilot model-based tools on a convincing scale.

The panel believes that the technologies required to pilot concept engineering are sufficiently mature to recommend an FOB protection concept engineering effort. This should be started immediately to address this high-priority warfighting need.

Finally, the wide array of technology tools discussed above will not have the maximum benefit to rapid capability projects unless a conscious effort is made to develop a roadmap specifically geared toward such projects. Therefore, the development of a roadmap for R&D in rapid fielding capability tools is recommended.

To reiterate a key point made earlier, although this study focused on the application of tools to satisfy challenges in rapid fielding programs, technology alone cannot make these programs operate more effectively or efficiently. Implementation of the recommendations from this study should be done in concert with implementing recommendations from other studies to improve process, personnel, and cultural challenges that significantly impact the department's ability to rapidly provide capabilities to the warfighter.

Glossary

Acronyms

BPMN	Business Process Modeling Notation
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CBRNE	Chemical Biological Radiological Nuclear and high-yield Explosives
COCOM	Combatant Command
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
CREATE	Computational Research and Engineering Research Tools and Environments
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director, Defense Research & Engineering
DoD	Department of Defense
EMI	Electromagnetic Interference
FFRDC	Federally-Funded Research and Development Center
FITE	Future Immersive Training Environment
FOB	Forward Operating Base
ISR	Intelligence, Surveillance, Reconnaissance
JCTD	Joint Capability Technology Demonstration
JUON	Joint Urgent Operational Need
M&S	Modeling and Simulation
MBE	Model-Based Engineering
MDA	Model-Driven Architecture
MDSD	Model-Driven Software Development
MRAP	Mine-Resistant Ambush Protected
OMG	Object Management Group
POR	Program of Record
RDF	Resource Description Framework
SE	Systems Engineering
SIMEX	Simulated Exercises
SME	Subject Matter Expert
SoS	System of Systems
SysML	Systems Modeling Language
TIGR	Tactical Ground Reporting
TTP	Tactics, Techniques, and Procedures
UARC	University-Affiliate Research Center
UAV	Unmanned Aerial Vehicle
UML	Unified Modeling Language
UxV	Unmanned Vehicle (unspecified type)
V&V	Verification & Validation
W3C	World Wide Web Consortium

Terminology

- Rapid Capability Fielding: *Streamlined projects seeking to field capability in less than 24 months.*
 - *This could be in response to a stated need of a combatant commander or in anticipation of a potential need*
- Technology Tools: *Software, algorithms, models, simulations, manufacturing hardware/software, and associated processes that support the full life cycle of rapid development*

Appendix A: Terms of Reference

Objective:

Provide specific recommendation to DDR&E regarding technological opportunities to significantly decrease the development time and increase the operational effectiveness of rapidly fielded capabilities.

Background:

The recent past has highlighted the need for the DoD to be able to rapidly field capabilities in anticipation of emerging threats and/or in response to rapidly changing enemy tactics and techniques. This trend is expected to continue in the foreseeable future as irregular warfare persists and the globalization of technologies fuels our enemies' capacity to implement and adapt solutions in very short order. Consequently, there is an ongoing emphasis within the DoD as a whole and individually within the Services and Combatant Commands to evaluate, evolve, and/or transform aspects of our operations to better service the need for rapid capability fielding.

A large number of studies have been conducted in this regard, primarily focused on developing recommendations for organizational, process, and manpower improvements. As the Department adopts and implements some or all of these recommendations, the DDR&E is seeking to identify and further develop the supporting "toolbox" of technical capabilities that will underpin the successful implementation of rapid fielding capabilities. These technical capabilities may include: modeling and simulation to support rapid design, fabrication, and testing; system engineering tools to rapidly design and re-design complex systems; rapid prototyping; and manufacturing processes and tools to speed development and/or enable rapid manufacturing "cross-over".

Each expert will develop his or her own analysis and recommendation, with assistance from Analytic Services Inc. (ANSER). ANSER will prepare a summary of expert's findings and recommendations; experts will be invited to review the draft product prior to submission to DDR&E. Meetings of experts will be held at ANSER to provide opportunities to review any information that is requested and benefit from discussion among the experts.

Each expert participant will be able to make any personal use of their inputs he or she desires, subject only to classification restrictions.

Study questions:

1. What are the current technical tools used in both the defense and commercial industries to rapidly design, fabricate, test and validate new systems?
 - a. Pay particular attention to modeling and simulation tools to support rapid design, fabrication, and testing; system engineering tools to rapidly design and re-design complex systems; and manufacturing processes and tools to speed development.

- b. Are there tools that would allow for end to end rapid development, to include such functions as CONOPS development, interoperability, and testing?
2. For each of these tools, assess their current capabilities and limitations for DoD rapid fielding needs.
3. What are the emerging technology opportunities? Identify the technical leaders in these areas and propose approaches to validate the impact of these tools.
4. How might these technology opportunities be best developed? Program scope, scale, and schedule? Suggestions as to how this might best be done, and by whom are invited.
5. Is there any way to tailor current tools, techniques, models, methodologies, best practices, etc., to achieve better rapid fielding capability immediately?

Security:

Discussions will be held at the unclassified level. Areas that the group feels should be addressed at higher classification will be addressed to the government sponsor for further consideration.

Study Membership:

The study team will be led by Mr. Jim Carlini, and will be comprised of a small group of senior leaders and technologists with extensive experience in product development, relevant technologies, and/or commercial practices. Initial participants with varying degrees of participations are expected to be:

- Jim Carlini, Study Technical Lead
- Mark Burgess, Boeing Research and Technology Chief Engineer [Defense/Aerospace, Systems Engineering]
- Mr. Yngvar Tronstad, EVP and Chief Scientist for Cogility Software [Software]
- Bran Ferren, Chief Creative Officer and Co-Founder, Applied Minds [Engineering, R&D]
- Alan Rudolph, CEO, Adlyfe, Inc. [Bio.]
- Dennis Roberson, Vice Provost, Illinois Institute of Technology [Commercial Wireless Technology]
- Dinesh Verma, Professor & Dean, Stevens Institute of Technology [Systems Engineering]

Note, additional personnel may be added to the study team as necessary.

Meetings:

The team should anticipate three meetings for this study. Additional meetings may be scheduled as needed. The team should also plan on at least weekly conference calls or web conferences and other coordination as necessary. Dates and times of meetings and other coordination items will be established by the Plan of Action and Milestones (POAM).

Sponsorship, Execution, and Administration:

The study is sponsored by Mr. Zachary Lemnios (Director, Defense Research and Engineering). Ms. Kristen Baldwin (Deputy Director, Strategic Initiatives) will be the DDR&E Lead. Key Department Stakeholders will be engaged during the study to ensure the team is informed of current DoD activities. The study will have support from ANSER. ANSER shall provide both administrative and technical support to the study team and meetings. A senior ANSER staff member will serve as the Executive Secretary. ANSER will facilitate any background and overview briefings needed by the study team or any additional information that is requested and support the production of status reports, meeting minutes, briefings and the final report. ANSER will execute consulting agreements as necessary with study participants.

Schedule and Cost:

This will be a 60 day study with a 30 day interim brief. One week after the approval of this ToR, ANSER will develop a detailed POAM in coordination with the study group.

Deliverables

The study group will provide its findings and recommendations in an interim brief (30 days after ToR approval), a final brief (60 days after ToR approval), and a final report (date to be determined). Some additional follow-up may be required upon request from the DDR&E leadership. The report should include an overview, a list of references and definition of terms.

Appendix B: Panelists

Jim Carlini, Study Lead, *Consultant, former Vice President for Advanced Development, Northrop Grumman Electronic Systems*

As the founder of James Carlini Consulting, Mr. Carlini provides consulting services to a wide range of government and industry national security organizations. Services provided include strategic planning, systems analysis, concept development, program formulation, technology transition, and technology roadmapping. From 2002-2006, Mr. Carlini was responsible for the strategic planning, capture, and execution of advanced development programs in the Electronic Systems Sector of Northrop Grumman Corporation. He had cognizance over advanced development programs in the areas of force protection, strike and combat, advanced surveillance systems, chemical and biological defense, land combat, and navigation systems. From 1998-2002, Mr. Carlini was the Director of the Special Projects Office at the Defense Advanced Research Projects Agency (DARPA). Mr. Carlini formed the Special Projects Office to develop, focus, and apply advanced technologies and systems to emerging national security and military challenges. Mr. Carlini also served at DARPA from 1995-1998 as a Program Manager, the Assistant Director of Missile Technologies, and the Deputy Director of the Sensor Technology Office. Mr. Carlini is currently a member of the United States Army Science Board and a consultant to the United States Air Force Scientific Advisory Board. He holds a Master of Science in Electrical Engineering (The Johns Hopkins University, 1993) and a Bachelor of Science in Electrical Engineering (Drexel University, 1987)

Mark Burgess, *Boeing Research and Technology Chief Engineer*

Mark Burgess is the chief engineer of Boeing Research and Technology where he is responsible for ensuring technical quality and engineering excellence for the Boeing Research and Technology organization. He also ensures that Boeing Research and Technology, as the advanced research and development arm of The Boeing Company, has the right people, processes, and resources in place to enable successful results and transfer of technology throughout the Boeing enterprise. Prior to this assignment, Mr. Burgess supported the Joint Strike Fighter (JSF) program. His previous positions on the JSF program include St. Louis site director and X-32 Air Vehicle Analysis and Integration team leader. Mr. Burgess holds a Bachelor's and Master's of Science degrees in Aeronautical Engineering and a Master's of Science degree in Industrial Administration, all from Purdue University.

Dennis Roberson, *Vice Provost, Illinois Institute of Technology and former CTO, Motorola*

Dennis Roberson is Vice Provost and Executive Director of the Institute of Business and Interprofessional Studies, as well as Acting Director of the Jules F. Knap Entrepreneurship Center and Research Professor of Computer Science at the Illinois Institute of Technology. In this capacity, he is responsible for its undergraduate business and related co-curricular programs and is concentrating on the entrepreneurship, leadership, and technology based projects. Professor Roberson is also responsible for assisting the university in technology transfer and the development of new research centers and business ventures. Prior to IIT, he was Executive Vice President and Chief Technology Officer of Motorola. Professor Roberson has an extensive corporate career including major business and technology responsibilities at IBM, DEC, AT&T, and NCR. Professor Roberson has undergraduate degrees in Electrical Engineering and in Physics from Washington State University and an MSEE degree from Stanford.

Yngvar Tronstad, *Executive Vice President and Chief Scientist, Cogility Software*

Mr. Tronstad has over 25 years of experience in defining, developing and deploying mission critical systems. As a founding technologist, he conducted research and development of world leading System Engineering (SE) software products used widely today in the military and aerospace industries. Mr. Tronstad has been instrumental in the extension of core Software Engineering technology with Object-Oriented Enterprise Software Applications into the commercial market. He is a former Partner and Managing Director at KPMG Consulting, (now Bearing Point), and the former Chief Scientist and technology founder of Ascent Logic Corporation. He is a (Ret.) Royal Norwegian Navy CDR and holds a BS in Military Studies from the Royal Norwegian Naval Academy and a MS in Underwater Acoustics from United States Naval Postgraduate School.

Dinesh Verma, *Dean, School of Systems and Enterprises, Stevens Institute of Technology*

Dr. Verma is currently serving as Dean of the School of Systems and Enterprises and Professor in Systems Engineering at the Stevens Institute of Technology. He concurrently serves as Scientific Advisor to the Director of the Embedded Systems Institute in Eindhoven, Holland. Prior to this role, he served as Technical Director at Lockheed Martin Undersea Systems, in Manassas, Virginia, in the area of adapted systems and supportability engineering processes, methods and tools for complex system development and integration. Before joining Lockheed Martin, Verma worked as a Research Scientist at Virginia Tech and managed the University's Systems Engineering Design Laboratory. While at Virginia Tech and afterwards, Dr. Verma continued to serve numerous companies in a consulting capacity, to include Eastman Kodak, Lockheed Martin Corporation, L3 Communications, United Defense, Raytheon, IBM Corporation, Sun Microsystems, SAIC, VOLVO Car Corporation (Sweden), NOKIA (Finland), RAMSE (Finland), TU Delft (Holland), Johnson Controls, Ericsson-SAAB Avionics (Sweden), Varian Medical Systems (Finland), and Motorola. He served as an Invited Lecturer from 1995 through 2000 at the

University of Exeter, United Kingdom. His professional and research activities emphasize systems engineering and design with a focus on conceptual design evaluation, preliminary design and system architecture, design decision-making, life cycle costing, and supportability engineering. Dr. Verma received a PhD and M.S. in Industrial and Systems Engineering from Virginia Tech.

Bran Ferren, Co-founder, Applied Minds and former President, Walt Disney Imagineering

Bran Ferren is the co-founder, Co-Chairman and Chief Creative Officer of Applied Minds, a company that provides advanced technology, creative design, and consulting services to a variety of clients, including The Walt Disney Company, NASA and GM. Before founding Applied Minds, Ferren held various leadership positions, including president, at Walt Disney Imagineering, the company's R&D division. Bran Ferren speaks from unique experience on the art and science of the imagination, and how to organize for innovation. He has a distinguished career of contribution to business and product development, film and entertainment, aerospace and other sciences, winning many awards, including three Academy Awards for technical achievement.

Michael McGrath, D. Sc., Mark Weitekamp and JoAnne Paynter from Analytic Services Inc. (ANSER) provided technical and administrative support to the study team.

Appendix C: Information Gathered by the Study Panel

Government Perspectives

<u>Presenter/Organization</u>	<u>Topic</u>
Bobbe Desmond, Michelle Bowen/MRAP	Rapid Fielding Program Case Study: Mine Resistant Ambush Protected (MRAP)
Steve Kundrat/USSOCOM, Systems Engineering and Integration	Rapid Capability Fielding at USSOCOM
Lt COL Scott Nowlin, Technology Transition Office, USAF	AF Rapid Capability Fielding Technology Tools Snapshot
Carl Siel, ASN(RDA)CHSENG	Navy Perspective on Rapid Capability Fielding Tools
Robert Schwenk, Office of the Assistant Secretary of the Army (AT&L)	Army Rapid Capability Toolbox Suggestions
John Fischer, Laboratories Office USD (ST&L)/DDR&E/RD	DoD Laboratory Rapid Prototyping Capabilities
Ben Riley, DDR&E Rapid Fielding Directorate	Sample Rapid Capability Development Programs
Joseph Hoeg & Frank Mazur, NAVAIR	NAVAIR Rapid Prototyping Capabilities
Director, G3 Current Operations RDECOM	Army Rapid Prototyping Capabilities – Warfighter Focused (RDECOM)
Adele Ratcliff, TanTech, OSD	Tools for Rapid Manufacturing
William Coblenz & Art Bruckheim, DARPA	Digital Direct Manufacturing & High-Impact Technologies for Military Manufacturing
Brench L. Boden, USAF ManTech (AFRL/RXMT)	USAF Perspective on Tools Needed for Rapid Manufacturing
Paul Eremenko (DARPA Tactical Technology Office	Design Approaches for Complex Systems
Chris Gaughan, US Army RDECOM RDST-TT	Integrated Modeling and Simulation Environments
John Livingston, USAF Capabilities Integration Directorate	Model Based Engineering
Dan Kaufman, DARPA	RealWorld® Capabilities as a Virtual Environment

<u>Presenter/Organization</u>	<u>Topic</u>
Clarke Lethin, Technical Manager, ONR	Future Immersive Training Environment (FITE) JCTD
Peter Lee, DARPA	Transformational Technologies
Paul Jeskiewicz, OSD P&R	M&S Capabilities to Improve Personnel Readiness
Dennis Baum, OUSD AT&L/A&T/PSA	M&S Capabilities
John Moore, USN	Navy M&S Capabilities
Jesse Citizen, OSD ATL	DoD M&S Capabilities
Jim Blank, JFCOM Experimentation Cell	M&S Support to Specific Solution Development
Chip Ferguson, JMETC	T&E to Meet Joint Operational Needs
Doug Post, Higher Performance Computing	M&S Capabilities
Dennis Wisnosky, OSD DCMA	Service Oriented Manufacturing
William Decker, DAU MSCO	DAU Modeling Tools
Bill Beasley, DDR&E Rapid Fielding Directorate	Urgent Needs Data

Industry and Academia Perspectives

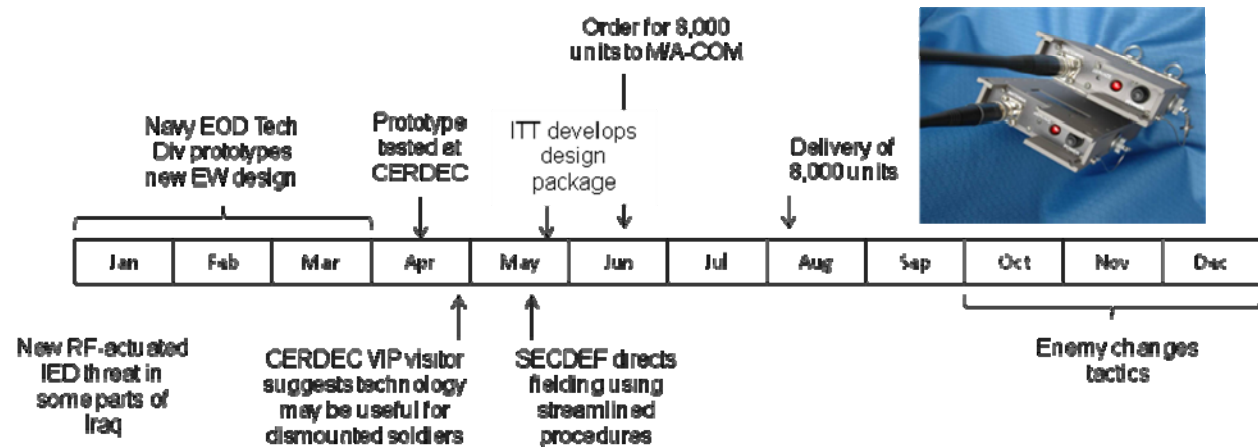
<u>Presenter/Organization</u>	<u>Topic</u>
Dennis Kalajainen, IBM	Tailoring SE to Fit Project Scope
Terry Heng, President, Uniquesoft, LLC	Software Models to Automated Code Development and Testing
Andy Turner, Nokia	Product Architectures
Dell Lundsford, Total Immersion Software	Gaming Technologies for Rapid Concept Engineering
Yngvar Tronstad, COGILITY Software	Rapid Development of Composite Applications Using MDA and SOA and EDA
Mark Burgess, Boeing Research & Technology	Future of Engineering – Imagining the Future: The World of Engineering Work
James Fallon, COBHAM Defense Electronic Systems	Tapping Rapid Commercial Manufacturing Capabilities
Sandy Friedenthal, Lockheed Martin	Model Based Systems Engineering using SysML

<u>Presenter/Organization</u>	<u>Topic</u>
Jack Harris, Advanced Manufacturing Technology, Rockwell Collins	DDR&E Technology Toolbox Study Briefing – The Model Based Enterprise
Susan Rose, Systems and Software Consortium	SSCI Industry Report on Current and Future Tools to Support Rapid Capability Fielding
Jack White, TechTeam Government Solutions	Service Oriented Manufacturing
Nick Karangelen, Trident	CAD to Virtual Environment Tools
Andy Dallas, SOARTech	Integrating Human Behavior into Virtual Environments
Michael Zyda, USC GamePipe Laboratory	Virtual Environments
Jon Wade, Stevens Institute of Technology	Systems Engineering Revitalization Efforts
Ali Mostashari, Stevens Institute of Technology	An Overview of Modeling and Simulation Tools, Current and Future Directions
Preston Marshall, ISI USC Viterbi, School of Engineering	Responsive and Automated Design and Manufacturing
Professor de Weck, MIT	Strategic Engineering: Designing Systems for an Uncertain Future
Donna Rhodes, MIT	Value Driven Engineering
Gerrit Muller, Buskerud University College, Kongsberg, NO	Rapid Development in Consumer Industries from a Technology Perspective
Hugh Musick, IIT Institute of Design	Understanding User-Centered Design
Randall Shumaker, University of Central Florida	Simulations and Cultural Modeling
John Sokolowski, Virginia Modeling, Analysis and Simulation Center (ODU)	M&S to Support Acquisition Decisions

Appendix D: Rapid Fielding Case-Study – Warlock Blue

Warlock Blue is a handheld jammer, fielded as a rapid response to a particular class of Improvised Explosive Device (IED) threats. The program is an example of government-industry teaming and of extremely rapid production in quantities sufficient to meet an urgent operational need.

Background: The Navy Explosives and Ordnance Disposal (EOD) Tech Division at Indian Head, MD has a mission to develop Electronic Warfare (EW) countermeasures that can render RF-triggered threats ineffective. This government activity has in-house design capability, and continually upgrades EW systems to insert new technology and meet rapidly evolving threats. NAV EOD Tech Division generally looks to industry to produce components and systems in fieldable quantities.



Timeline

In **late 2004 and early 2005**, a new type of RF actuated IED became prevalent in some parts of Iraq. This was not a surprise to the ongoing EW program, and was quickly addressed by the Navy's design team, in close coordination with Army users. In January through March of 2005, NAV EOD Tech Div developed a prototype of a new EW design well suited to this particular threat. This design was intended to be inserted as a module in the EW systems in the field at the next upgrade point.

In **April 2005**, the Navy prototype was sent for testing at the Army Communications and Electronics R&D Center (CERDEC) in Ft. Monmouth, NJ. It was found to be effective against the class of threat seen in the field, and discussions were initiated on how best to get it into EW systems in the field. An official visitor to CERDEC suggested packaging the system for use by dismounted soldiers. There was no Urgent Need Statement from the user or Concept of Operations (CONOPS) for such a wearable device, but the concept was considered feasible by the design team. The wearable device was designated Warlock

Blue, as a member of the Army family of Warlock jamming systems. The Navy contracted with ITT Defense to turn the prototype design into a fully documented “build to” data package.

In **May 2005**, the Secretary of Defense directed that 10,000 units be fielded in 60 days, using streamlined acquisition procedures. This was a difficult challenge, since traditional defense contractors estimated a lead time of 8-12 months to deliver the first production items. A non-traditional (commercial) supplier, M/A COM division of Tyco Electronics, was given the design package for review. M/A COM estimated that the delivery time could be met using commercial practices and tooling.

A streamlined competition was held in **June 2005**. M/A COM won a contract for 8,000 of the units. The company viewed it as a “patriotic production” effort. The M/A COM team coordinated closely with Navy and Army technical experts to modify the design slightly to use readily available parts. The production team worked nights, weekends and holidays, and M/A COM delivered **8,000 units 54 days after receipt of order** – an extraordinary achievement even by commercial standards. Success was attributed to effective government/industry partnership, streamlined procurement, and fast moving commercial manufacturing and supply chain procedures.

Results and Lessons for the Rapid Fielding Toolbox Study

Representatives of M/A COM (now a division of Cobham PLC) briefed the Study Panel. They reported that:

- **The rapid contracting authority delegated by the Secretary of Defense was essential to the success of the project.** It is important to note that contractual and business processes have to be in place to enable rapid fielding. While this study focuses on the tools and methods aspect of rapid fielding, the fact is that these tools and methods will not be used in a vacuum and must be fully integrated into streamlined acquisition processes.
- **No special tools were used in the project beyond those used in normal commercial practice for products such as police and fire radios.** Coordination and collaboration with industry partners will often dramatically reduce the level of effort required for using in-house capabilities only.
- **Warlock Blue was a crash effort (54 days), but a normal commercial production run of an item of this complexity would have taken on the order of 120 days.** Still much better than the 8-12 months estimated by defense suppliers. This emphasizes the point that, with appropriate partnerships and enabling processes, the time required for rapidly fielding projects can be dramatically reduced.

The study panel’s conclusion is that commercial suppliers who specialize in being fast to market can be very effective complements to DoD’s in-house capabilities, assuming the product is within the technical competence of a commercial supplier.

A representative of NAV EOD Tech Division was interviewed by the study panel. He pointed out that:

- **The government-industry teaming was highly effective, and the high level DoD attention and priority helped move things at unusual speeds.** However, it is highly improbable that SecDef will provide this level of attention to all rapid fielding projects.
- **Warlock Blue was a relatively simple item. More complex and specialized EW equipment would require capabilities that exist only in specialized defense suppliers.**
- **The enemy rapidly changed tactics and moved on to new threats that were beyond Warlock Blue's capability envelope.** Therefore, it is necessary to consider the expected life cycle time for rapid capabilities. If the life cycle time desired is longer than a given design concept might allow, consideration should be given in the early stages of the engineering process to ways to impart flexibility or upgradeability into the overall system design.

The lesson for the study is that the “threat—countermeasure—counter-countermeasure” nature of EW makes it a good candidate for a persistent Concept Engineering environment. Physics based models, CONOPS simulation and perhaps hardware-in-the-loop capability would make such an environment most useful in exploring alternative solutions, anticipating needs, and keeping pace with an agile enemy. The Capability Engineering environment that couples with it can leverage existing government, defense industry and commercial industry capabilities for detailed design and production.

Appendix E: System and Software Consortium Workshop Supporting the Rapid Fielding Study

In October 2009, the Systems and Software Consortium held a workshop on Technologies for Rapid Fielding. Participants represented a broad cross section of the consortium membership, and provided a valuable industry input to the DDR&E study group. The workshop was intended to identify tools, technologies, and methods to enable rapid fielding of systems. Workshop participants proposed and then collaboratively analyzed a wide range of tools, methods, and technologies. The participants divided into working groups to conduct this analysis. Each working group focused on a different area, and provided references and recommendations for tool use to improve system development and flexibility.

The summary level recommendations of the workshop were:

- Encourage the use of modeling and simulation tools to expedite the development life-cycle activities
- Promote the creation and maintenance of common repositories (and common infrastructures) to achieve consistency, promote information sharing, and encourage stakeholder interactions
- Remove stovepipes and other barriers to information sharing and allow the open source community to participate
- Incentivize tool integration
- Support demonstration labs to encourage engineering advancements
- Enable greater (and richer) interaction between developers and user community to promote greater understanding of capability needs and system tradeoffs
- Acknowledge the benefits of automated (or auto-assisted) development environments for expediting the development process
- Encourage the implementation of iterative/incremental life cycles that provide on-going feedback and continuous system validation and verification
- Prioritize system attributes such as flexibility and robust designs
- Leverage the advances in virtual reality engineering to bridge the gap between reality and expectation

Workshop documents provided by the Systems and Software Consortium included investment opportunities and specific recommendations in the eight categories below.

a. Modeling and Simulation Tools

1. Use requirement and design models to automate testing
2. Use M&S to support more rigorous design analysis. This may include making system design trades using design models, analyzing system behavior using subsystem interface modeling, using process, performance, analysis models to improve efficiency, and visualizing hardware designs using a virtual system simulation.
3. Use M&S to develop a more accurate system definition. Requirements models may be used to validate needed system capabilities verify requirement specifications.
4. Use M&S to support faster implementation. Specifically, models can be used as the basis for automatically generating code from design models.
5. Expedite software development using/reusing SW frameworks.

Investment opportunities:

- Invest in options (e.g., integration lab) to enable greater tool integration
- Encourage the expanded use of models and simulations (by acknowledging it is a best practice)
- Develop modeling guidelines and develop common set of models and frameworks
- Incentivize sharing of models among stakeholders (e.g, within the supply chain and across organizations and companies)
- Fund the investigation and expanded use (if warranted) of virtual simulations
- Invest in education and training
 - Identify modeling and simulation best practices
 - Provide usage guidelines to support adoption

b. Analysis of System Tradeoffs

1. Enable greater interaction between the end users and the developers (especially early in the life cycle)
 - Establish a dialog among system stakeholders to converge on a common, shared vision of system capabilities
 - Encourage prioritization and on-going reprioritization of system capabilities as the system evolves
2. Provide technologies for understanding system tradeoffs (early in the life cycle)
 - Invest in technologies that help accurately evaluate the benefits and costs associated with fielding specific capabilities (e.g., models)
 - Support design for flexibility and testability

Investment opportunities:

- Promote extensible architecture approaches
- Include technical enablers (e.g., interface model generation) as part of funded work

- Consider leveraging new technologies (e.g., inversion of control)
- Provide education and skill development

c. Common Infrastructure/Repositories

1. Establish and maintain common repositories for non-proprietary life cycle artifacts that can be searched. These repositories should ensure appropriate artifacts are included and verify the relevance, accuracy, and appropriateness of the contents. There must also be a mechanism where classified artifacts can be shared within reasonable security restrictions.
2. Establish a set of common infrastructure assets (e.g., design patterns, guidelines, measurement constructs). All stakeholders must be provided access to and encouraged to use these assets. One way to do this is to encourage stakeholders to contribute their own assets.

Investment opportunities:

- Invest in governance structure (e.g., CCB)
- Invest in defining the metadata and other structures needed for standardization
- Fund the design/development/ deployment of common repositories
- Exert pressure to support standardization

d. Information Sharing

1. Break down stovepipes and remove barriers to information sharing. This requires that the Department provide the tools and infrastructure needed to promote information sharing and create incentives to encourage information sharing. The Department must also remove, or at least lessen, the social, political, and economic barriers that inhibit information sharing which will likely include new policies and processes. To do this, there must be a rationale for inhibitors that prevent (or discourage) information sharing so arbitrary barriers can be removed. And this requires appropriate leveraging of the open source community.

Investment opportunities:

- Identify the critical limitations of information sharing and remove as many other barriers as possible (e.g., create a secure mechanism for information sharing vs. eliminate any sharing of secure information)
- Provide motivation for information sharing
- Leverage the open source and OpenSocial communities

e. Tool Integration

1. Develop tool chains that are integrated and interoperable. These tool chains should provide end-to-end tool support for the entire development life cycle.

Investment opportunities:

- Exert pressure on tool manufacturers to develop and implement standards to support interoperability

f. Demonstration Labs

1. Fund development labs to explore technologies that facilitate rapid fielding of capabilities. This will include developing a virtual test bed, investigating and evaluating emerging tools, piloting technologies, and providing assessments of potential benefits

Investment opportunities:

- Work with industry to jointly standup a demonstration lab
- Provide needed infrastructure for establishing a virtual test-bed

g. Automated Development Environments

1. Provide development platform(s) that expedite the development activities
 - Leveraging and reusing tools, artifacts, functionality, etc. across programs/projects
 - Establishing enforcement of the process and workflow rules
 - Automating development activities (e.g., code generation, test development)
 - Providing plug-and-play environments
 - Leveraging SW languages appropriate for the development context (e.g., domain specific languages)
 - Utilizing frameworks to promote consistency and reuse (e.g., architectural frameworks and design patterns)

Investment opportunities:

- Define a set of common business functionalities that can be applied in different domains
- Create a Center of Excellence for governance and education
- Provide guidance on the tools and their capabilities to support tool selection and usage

h. Virtual Reality Engineering

1. Provide direct communication with stakeholders and ensure voice of customer.
2. Provide an immersive, persistent, interactive, and managed virtual workspace. This will provide a rich communications vehicle and will provide opportunities for exploiting current virtual technologies.
3. Provide continual system validation by considering views appropriate for each unique stakeholder group and developing a context for stakeholders to evaluate system capabilities.

Investment opportunities:

- Support the creation of standards working groups for defining content and interoperability standards
- Develop a virtual world infrastructure to maximize reuse of virtual components
- Develop reusable virtual components (and share with stakeholders)
- Establish a Center of Excellence as virtual presence to experiment and build capabilities
- Fund pilot projects and host outreach events

Appendix F: User-Centered Design

User-centered design (UCD), also known as human-centered design (HCD) is defined by *ISO 13407: Human-centered design process (1999)* as “an approach to interactive system development that focuses specifically on making systems usable. It is a multi-disciplinary activity.”

UCD takes a systems approach to problem solving. The tools and processes are used by industry and government to better understand, identify, and articulate users’ needs which then enables designers to provide better products. In addition to the design of physical products, UCD has also been successfully applied to non-physical products such as software and processes. For the Department of Defense, UCD provides tools and processes that will likely enable the Department to conduct more accurate assessments of warfighter needs. The improved accuracy of needs assessments is a critical requirement for quickly providing effective and *usable* systems to the battlefield. In order to do this, the Department must create an environment and supporting processes for the routine collection and utilization of user-centered feedback. These processes and tools will help to systematically anticipate needs and user-centered design factors that can be iterated with CONOPS.

Some of the tools and processes to be explored include:

1. **POEMS.** An observational framework which focuses on people, objects, the environment, messages, and services.
2. **Conceptual Design Process.** This is a process for developing and implementing a system concept and progresses in the following stages: definition, research, analysis, synthesis, and realization.
3. **Tools suites for process steps.** Each process step (e.g. definition) has an associated suite of support tools (e.g. definition statements, concept space framing, trend matrices, and precursor analysis for definition). The associated tools for each step should also be considered for the development of a UCD strategy.

Figure 11 illustrates the applicability of UCD/HCD tools and analytic methods for use in specific research projects. For example, generic analysis tools such as scoring and clustering analysis is very useful in researching user activities and behaviors. As illustrated in Figure 11 there are a large number of tools that are applicable across research domains focused on users, products, and business practices.

analysis methods and tools		targets			users	products	business
					activities / behaviors perceptions / responses modes interactions culture and trends	attributes performance configurations / systems technology / capabilities life cycles	strategies channels / markets industries identity / brand company structures
user analysis behaviors, experiences, culture	U 1	card sorting & analysis			■		
	U 2	behavioral segmentation & analysis			■		
	U 3	activity structuring & analysis			■		
	U 4	photo sorting & analysis			■		
	U 5	video bites analysis			■		
	U 6	analysis using user-frameworks			■		
generic	G 1	scoring & clustering analysis			■		
	G 2	keywords-in-database analysis			■		
	G 3	position mapping analysis			■		
	G 4	network analysis			■		
	G 5	interview/survey results analysis			■		
	G 6	magazines audit & analysis			■		
business analysis companies, market, industry	B 1	benchmarking and analysis					
	B 2	innovation landscape analysis					
	B 3	competitor & complimentor analysis					
	B 4	quantitative factoids analysis					
	B 5	era analysis					
	B 6	analysis using business-frameworks					
product analysis artifacts, services, environments, concepts	P 1	precursor analysis					
	P 2	flow analysis					
	P 3	semantic differential analysis					
	P 4	messages & communication analysis					
	P 5	space usage analysis					
	P 6	analysis using product-frameworks					

Figure 11. This matrix indicates the suitability of design analysis methods and tools for conducting specific types of research projects. Squares indicate that the method/tool is “very useful”, large ovals indicate that they are “useful”, and small ovals “somewhat useful”.

To move forward with the use of UCD/HCD, the department should conduct an assessment of the available HCD tools and processes and incorporate them into appropriate DoD processes. (Figure 11 is an example UCD/HCD tools and their applicability to various system activities or areas of interest). The processes should utilize forward-deployed resources such as Science and Technology Officers to engage fielded warfighters for UCD. The Department should further use the tool analysis to select, or if necessary modify or build, tools to integrate warfighter observations and analysis with engineering models. Finally, the Department should also consider how these tools and processes could be used within virtual environments, as a means to collect real-time observations from players in simulations or games.

Appendix G: DfX Tools

DfX tools represent a class of tools which are designed to enable specific aspects of the design process or non-functional system requirements. (DfX literally means “design for ‘X’”.)

As part of the effort, the panel collected a few DfX tools which they believe the Department should consider for incorporation into current processes. These include tools designed to support: manufacturing and assembly; cost; reuse/parts management; and obsolescence. Obviously, these tools represent only a small subset of the total tool space. In the time allotted, this study could not survey all of the available tools. It is recommended that the Department conduct such a survey with an eye toward ranking the utility along with the interoperability potential.

Tool	Description	Developer
DFMA® (also advertised as a Design for Environment tool)	Design For Manufacture and Assembly	Boothroyd Dewhurst, Inc
Calibre	Design for Manufacturing (ICs)	MentorGraphics
SEER-DFM	Design for cost	SEER - Galorath
SWMS	Design for Reuse / Parts Management	Unknown
Supportability Management Assessment & Report Tool (SMART)	Design for obsolesces	Resource Analysis Corporation

Appendix H: Hierarchical Abstraction and Auto-Design Tools

Currently, mechanical systems are designed at an individual part level through rudimentary, geometric construction techniques with some parametric/relational design automation. Integration is achieved through CAD visualization, auto-clash detection and model kinematics. Current integration techniques require lightweight, tessellated models and have limitations on the number of models and functionality available in the integration toolset.

However, auto design tools should eventually provide the ability to auto-generate design details, such as optimal load path mechanical primary structure definition, to the definition of individual piece parts ready for manufacture. The ability to visualize and functionally integrate large numbers of CAD artifacts on the fly is another desirable future state for auto-design tools. In order to do this, the Department must make investments in tools to take mechanical system CAD concepts and automatically develop manufacture-ready individual piece parts optimized for various design conditions. These tools should increase the fidelity and scale of models for integration, and abstract them into a single representation that is easily transferrable to the Concept Engineering Virtual Environment.

Model-Driven Software Development (MDSD) will take model artifacts from Concept Engineering as input and map them into detail design representations that can be automatically generated, functionally tested, and deployed on standards-based run-time environments. The trend is that the emerging standards for W3C, SysML, RDF, OWL, and BPMN are now being incorporated into the Object Management Group's (OMG's) MDA standard and should generate a new variety of vendor offerings which should be investigated, followed, and deployed as appropriate.

Below are examples of three industrial toolsets for auto-design:

- UNIQUESOFT and its Unique Soft Automation Development Environment has demonstrated greater than 50% improvement in elapsed time for development. In addition, the resulting code occupies less space than a comparable human coded system and the code runs considerably faster than that produced by direct human effort. The focus for this product is in the domain of complex embedded system with an approach which allocates most of the attention to the generation of correct requirements and limited effort needed to actually create and test correct code based on its built-in rules for completeness and correctness checking.
- Cogility Software with its Cogility Studio provides a pre-architected MDA solution for enterprise scale cross-cutting processes and data integration, with additional support for web services integration and complex event processing. Similarly, 50% improvement in speed of development, deployment and maintenance has been experienced due to built-in completeness and consistency checking.

- IBM's MDA offering is based on its large and diversified software acquisitions including Rational, Telelogic Rhapsody, and Popkins System Analyst. In addition, IBM has built up a tailorable template-based best practices suite for their approach.

Terminology

- **Direct representation** implies computationally complete specifications that shift the focus of software development away from the technology domain towards the ideas and concepts of the problem domain
- **Automation** use computer-based tools to transform domain specific models into implementation artifacts like: code, J2EE,.Net, and web-application
- **Standards** like OMG's MDA and W3C achieve more than reuse and interoperability; they encourage the emergence of an entire ecosystem of tool vendors addressing many different needs.

Appendix I: Use of Virtual Reality (VR) in Training Environments

Future Immersive Training Environment (FITE)

The Future Immersive Training Environment (FITE) Joint Capability Technology Demonstration (JCTD) was briefed to the panel in October 2009. Currently, the military training community has insufficient capabilities to train for soldiers on close combat tasks in a realistic and fully immersive environment that creates and reinforces complex decision making skills. There are several reasons for this shortfall. One reason is the current inability to provide adequate decision-making stimuli for highly repeatable and rapidly reconfigurable scenarios in an immersive environment. There is also a lack of adaptable, affordable, and integrated home station training capabilities which could be modified based on operational environment changes. Finally, there is a lack of high-fidelity virtual entities which can provide resource-effective complex population-based training environments. FITE is intended to address these problems.

By the end of FY10, FITE is intended to provide a training capability with integrated, interoperable, and immersive elements, which include visual, auditory, tactile, and olfactory stimuli. The environment should provide synthetic entities that are realistic, reactive, and dynamic. Interaction with these synthetic entities will enable realistic interaction and learning. Utilization of virtual environments for FITE will also provide the ability to create fully repeatable as well as reconfigurable scenarios. The virtual environment will be enhanced by real-time feedback from trainees which will help to improve the realism of the scenarios as well as certain synthetic elements. All FITE phases are intended to improve individual, team, and leader cognitive skills for decision making training.

FITE is employing a spiral development model. The first 2 “spirals” have been defined as the end state goal by the end of FY10. Spiral 1 is the development of individual worn virtual reality, while Spiral 2 includes both Individual Worn Augmented Reality and Facility-based Mixed Reality. See Figure I-12.



Figure I-12. First 2 defined phases of FITE.

Spiral 1 is intended to provide a VR integration of terrain, buildings, vehicles, weapons, and actors. This will be used to provide a more realistic training environment and enhance AARs for improved cognitive skills. Spiral 1 is designed specifically to support the Army dismounted soldier (infantry skills). Spiral 2 begins to combine real and virtual elements. Facility-based mixed reality would replicate battlefield conditions, cues, and attributes and enhance live training. VR could be used to add actors, obstacles, or other stimuli to a live exercise, requiring decision making in a real training environment. Individually-worn augmented reality would enable training at any location, not just at designated training facilities, though it could also augment facility-based training. Augmented reality would allow units to train on repeatable scenarios and also to reconfigure scenarios based on the current operating picture.

The technical approach for both initial spirals of FITE is to leverage and integrate existing technologies to produce the desired capability. These technologies include, but are not limited to: Virtual Battlespace 2 (VSB2), ExpeditionDI, RealWorld, and the Training Systems (TRASYS, USMC), Advanced Language Training System (ALTS) and Automated Performance Evaluation and Lessons Learned (APELL).

RealWorld

RealWorld is a DARPA project that enables the rapid creation of virtual reality simulations without the use of dedicated software programmers. This enables the user to rapidly, on the order of a few hours, create scenarios to support operational experimentation, training, and rehearsals in virtual space.

RealWorld enables the user to rapidly develop the virtual scenarios with a minimum of user inputs as outlined in Figure I-13. The starting point is the identification and importation of digital terrain from pre-approved sources (Step 1). The digital terrain forms the basis of the scenario simulation. If needed, the user can create and add details to the imported digital terrain, such as building interior layouts, the location of simple objects, walls, etc. (Step 2). A pull-down menu enables the user to populate the scenario with people, vehicles, and objects (Step 3). The RealWorld software automatically creates the scenario from the user's inputs (Step 4) and is immediately available to be used for mission rehearsal, training, tactical plan development, etc.

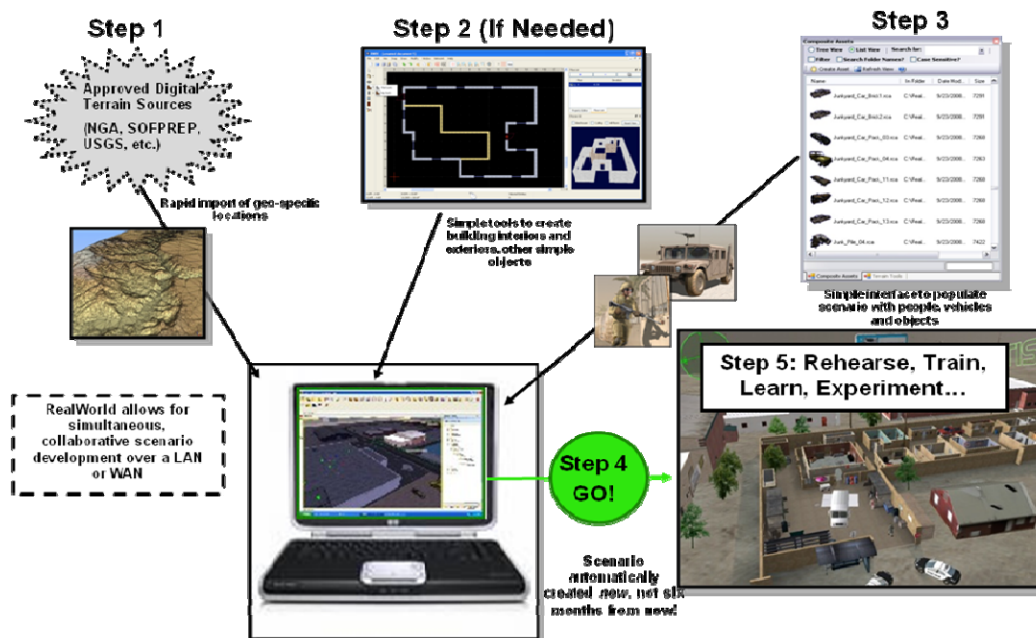


Figure I-13. Five primary steps required for RealWorld operation.

Scenario setup enables the user to select from a range of environmental (day/night/evening/weather) conditions and their impact on sensor systems. Weapon ballistics are based on the McCoy point mass ballistic model and mimic real ballistics within 1% of manufacturer's reports. Weapon selection includes environmental, weapon, and ammunition parameters to allow for existing weapons. These parameters also allow for handheld weapons, thrown objects, mortars, and future weapons to be incorporated into the game. Radar and electromagnetic environments models and databases can be integrated with RealWorld, to include linking to classified data.

RealWorld can also be integrated with other models. For example, when integrated with the Defense Threat Reduction Agency (DTRA) Chemical Biological and Nuclear (CBN) Dispersion Model, RealWorld can be used as a Real-Time Strategy (RTS) simulation. In this example, because RealWorld runs faster than real time, it can be used to evaluate a range of response actions. The output data can then be used by decision makers to select the option maximizing their objective.

Future improvements to RealWorld include the addition of voice recognition in which avatar actions are driven by spoken commands and computer generated behaviors for individuals and crowds. A built-in graphical user interface (GUI) based behavior editor will allow users to easily create new behaviors to meet evolving situations and it integrate RealWorld with a wide range of third party Artificial Intelligence (AI) models.

