APPLICATION OF SYSTEMS ENGINEERING TO RAPID PROTOTYPING FOR CLOSE AIR SUPPORT

John M. Colombi and Richard G. Cobb

Twenty-first century military operations have brought forth many new challenges for the Armed Forces of the United States. One such challenge is with new operating environments, where current systems are not always effective. While it is desirable to apply a *systems engineering* approach to best meet critical user needs, there may be a misconception that systems engineering requires a lengthy and detailed process not nimble enough for a rapid *prototyping* effort. This article describes how a classic systems engineering methodology was successfully tailored to the rapid development of potential material solutions to meet a critical operational need. Key observations are drawn from this experience and formulated into heuristics for tailoring systems engineering for future rapid prototyping efforts.

Keywords: *Systems Engineering, Prototyping, Rapid Product Development, Project Selection, Close Air Support*

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FMD
Friendly Marking Device
Allowing JTAC to quickly and accurately identify friendly ground personnel.
Friendly
Personnel: Ground Personnel
Location:
Status: Under Attack
CAS aircraft support: ENROUTE

Within the U.S. Air Force, a critical need has emerged for an added capability associated with the position of Joint Terminal Attack Controller (JTAC)—the Air Force airman trained to interface with aircraft to request and direct *Close Air Support* (CAS) attacks: to quickly pinpoint the location of friendly ground forces and communicate their location to CAS aircraft. Current operations in urban environments have placed JTACs in very close proximity to enemy forces and reduced the time to communicate with CAS assets. This close proximity and time compression, coupled with the complexity of the urban terrain, has made it difficult for the JTAC to direct an air attack using current systems and tactics while maintaining an acceptable fratricide risk. Thus, a Friendly Marking Device (FMD) that allows a JTAC to quickly and accurately identify the position of friendly ground personnel to CAS aircraft has emerged as a critical need.

Can a development effort be responsive enough to react to critical needs while still benefiting from the rigor of systems engineering?

Systems engineering offers a rigorous and repeatable methodology for translating a critical need into a viable solution (Defense Acquisition University [DAU], 2001). However, the perception that it necessitates a lengthy and detailed process may contribute to a misconception that the benefits of systems engineering must be traded off to be able to respond quickly to critical user needs. This perception/misconception juxtaposes a key question: Can a development effort be responsive enough to react to critical needs while still benefiting from the rigor of systems engineering?

This article attempts to answer that question by detailing an effort to tailor and apply systems engineering to a collaborative research project to rapidly prototype novel designs for the FMD. It describes the methods employed and offers key observations from the experience as lessons learned. From the lessons, heuristics are derived to guide the tailoring and application of systems engineering to future rapid prototyping efforts.

The JTAC user identified the critical need for a new way to mark the location of friendly ground forces. Under the auspices of the Air Force Research Laboratory (AFRL) Rapid Reaction Program—a program designed to match innovative research initiatives to critical needs—an effort began aimed at identifying and applying technology to the critical operational need, and resulting in the generation of a viable solution.

Method

PROJECT DEFINITION

The first step in defining the project was to assemble a core project team to guide the development effort. During this step, key stakeholders were identified—user/customer, project sponsor, systems engineers, and technology experts. The core team then worked to understand the operational need and, thereby, define the objective of the project: Develop, demonstrate, and transition a marking solution that enables a JTAC to establish a common point-of-reference with a CAS asset such that the CAS asset can attack an intended target while avoiding fratricide.

Constraining factors such as cost, schedule, technology maturity, resource availability, and operational limitations were clearly identified. Arguably, the most significant constraint on the project was a compressed schedule, inherent to the rapid reaction process. Driven by the desire to rapidly field a prototype, the project was constrained to 5 months. These constraints became fundamental elements driving several key evaluation and technical focus factors in our systems engineering process.

TAILORED APPROACH

After careful consideration of a variety of approaches, the classic Vee model described in Dennis M. Buede's (2000) text was tailored and selected as the basis for this project. Both the construct and execution of the model were modified to accommodate the constraints identified at the outset. The tailored Vee model (Figure 1) follows the general construct of the classic Vee model in that requirements solicitation and definition occurs down the left

FIGURE 1. TAILORED VEE MODEL

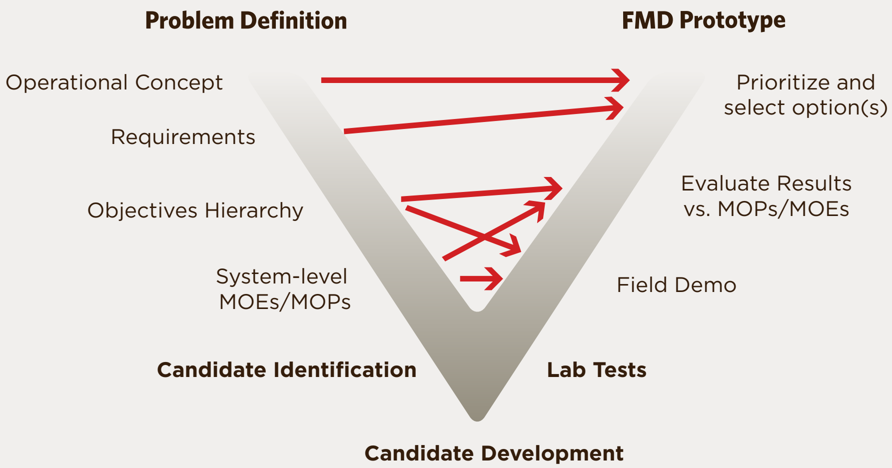


TABLE 1. SAMPLE USE CASE

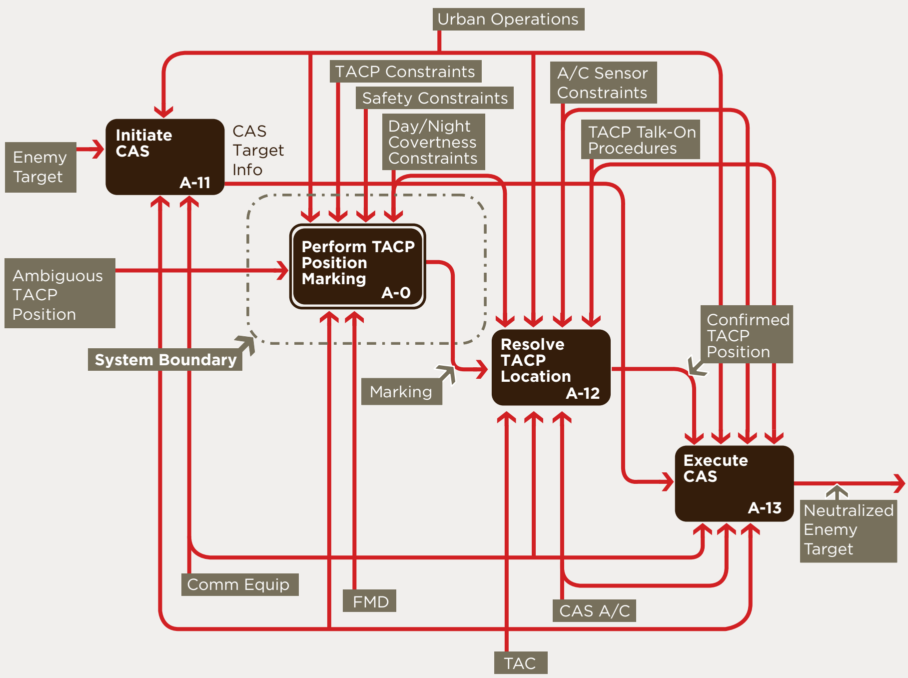
Urban Close Air Support Use Case	
Use Case Name	**Name:** Urban Close Air Support
	Brief Description: Describes the process directing a CAS attack in an urban environment.
Actors Involved	**Joint Tactical Air Controller (JTAC):** A certified servicemember who directs the action of aircraft engaged in close air support. • Goal—Accurately identify target and friendly forces to CAS aircraft.
	Close Air Support (CAS) Aircraft: Aircraft tasked to support close air support operations. • Goal—Accurately acquire target and friendly position.
	Air Support Operations Center (ASOC): The principal air control agency.
Preconditions	JTAC has communication with ASOC.
	JTAC has requested CAS support.
	CAS aircraft tasked to support the JTAC.
	CAS has aircraft in contact with JTAC.
Success Guarantee	CAS aircraft provide bombs on target.
	There is no fratricide of friendly forces.
	Collateral damage has been minimized.
Flow of Events	**Main Success Scenario:** Sequential, numbered steps to carry out the task.
Postconditions	**CAS Aircraft:** Provide bombs on target.

side (decomposition and definition), design engineering occurs at the vertex, and qualification occurs moving up the right side. An important element of tailoring as applied herein involves the recognition that the output of this tailored Vee model is not a validated system ready for use in the field. Rather it is an analytically tested and evaluated prototype that may be easily readied for production and, ultimately, used in the field.

PROBLEM DEFINITION

To state the problem in solution-independent terms, the definition process began by exploring the problem domain. After a literature search of typical CAS processes (Joint Chiefs of Staff, 2003; Pirnie et al., 2005), a set of elicitation questions was developed to help define a common understanding of the problem

FIGURE 2. EXTERNAL SYSTEMS DIAGRAM



with the user. These questions were then used as a basis for interviewing the user representative to build a definition of the problem.

It became evident the original problem statement did not capture another perspective that existed—that of the CAS pilot. To correct this, experienced CAS pilots were interviewed in a similar fashion to explore their perspective of the problem. After compiling the results of the interviews, the problem was stated as: The Joint Terminal Attack Controller (JTAC) lacks a covert means to quickly and accurately mark the location of friendly forces.

OPERATIONAL CONCEPT

The next step was development of the concept of operation for the solution—the vision of how the user might employ the resultant device. Borrowing from software engineering (Larman, 2004), the concept of a use case was employed to create a description of the sequenced actions that the user would likely follow in employing the FMD (Cockburn, 2001). Table 1 shows a simplified version of the basic use case for directing CAS attacks in an urban environment. (This is not a complete use case and is included for illustration only.)

Buede (2000, p. 144) states, "The single largest issue in defining a new system is where to draw the system's boundaries." As the project progressed, the value of defining and documenting the system boundary became evident, and the External Systems Diagram shown in Figure 2 was developed. Creating the External Systems Diagram helped highlight the key interaction in the operational concept—the use of the FMD to establish a common point of reference between the JTAC and the CAS pilot.

Requirements

With the appropriate data from the informal interviews of the user and other stakeholders as guidance, the system requirements were derived in detail from the operational concept. Once the initial set of requirements was identified, it was validated with the user and other stakeholders. In addition, the user

TABLE 2. USER REQUIREMENTS

User Requirements with Weights		
Type	**Requirements**	**Weights (1-10)**
Environmental	Weather Limitations	9
	Day/Night Limitations	10
Physical	Waterproof	8
	Shockproof	8
	Power Source	8
	Weight	10
	Size Dimensions	10
Operational (Signal)	Signal Duration	10
	Signal Covertness	10
	Signal Field of View	7
	Signal Range	10
	Accuracy Resolution	10
	Signal Spectrum	10
	System Compromise	2
	Unique Signal	2
	Signal Delay	10
Operational (System)	Ease of Use	8
	Modification Required	8
	Unique Signal Display	2
Acquisition (Long-term)	Long-term Unit Cost	5
	Product Feasibility	8
Acquisition (Short-term)	Estimated Cost	5
	Prototype Availability	7
	System Maturity	7

and other stakeholders provided weights for each requirement to determine their priority. Table 2 shows a sample of the system requirements (without the associated values, but with user weights).

OBJECTIVES HIERARCHY

In making a decision or evaluation, the development of a value model (in this case, an objectives hierarchy) enables the systematic identification and application of user value to multiple attributes of a decision. Following the approach described by Ralph L. Keeney (1992), a set of appropriate objectives was identified. Attributes to measure the degree to which the objectives are met were also developed. Finally, a hierarchy defining the relative weighting of the objectives was created (Figure 3).

The use case and user-expressed desires and constraints served as inputs into the development of the hierarchy. The objectives were developed by

FIGURE 3. SAMPLE OBJECTIVES HIERARCHY

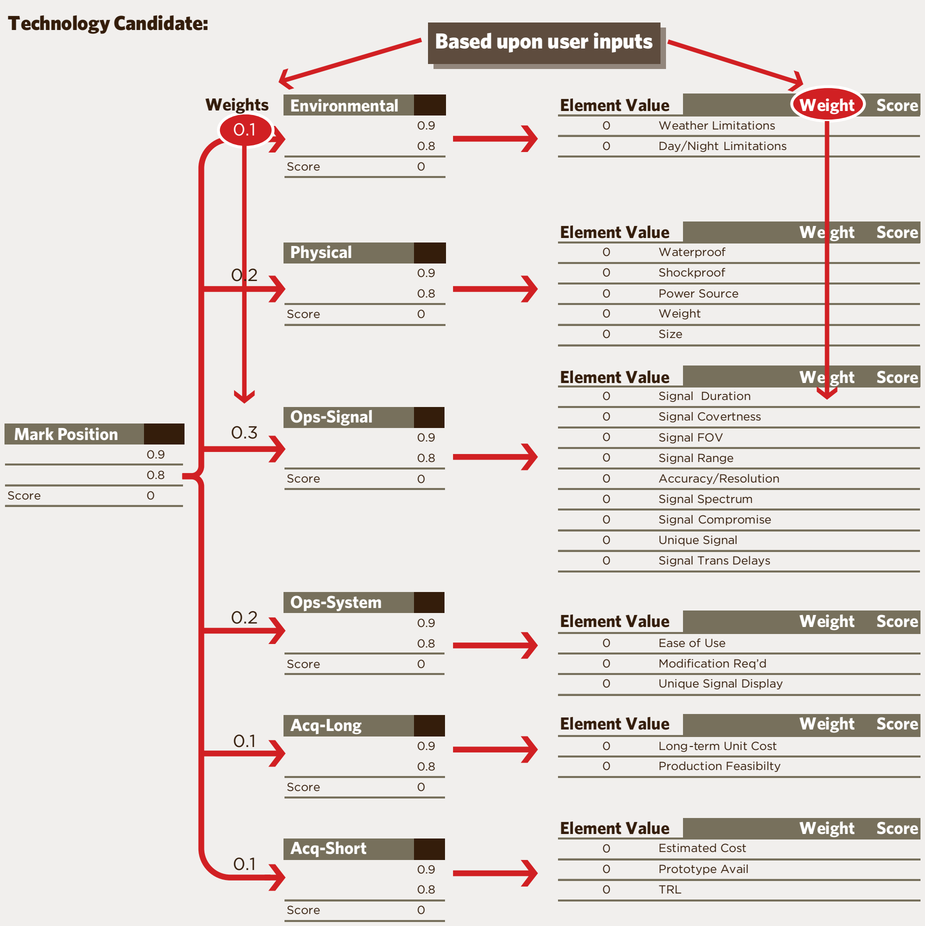
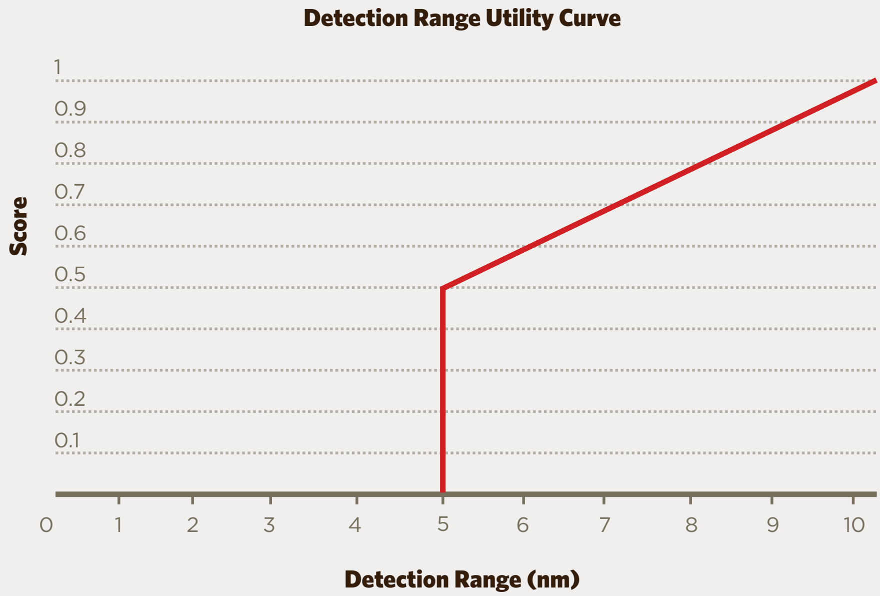


FIGURE 4. SAMPLE UTILITY CURVE



working closely with the user/customer. Once the basic hierarchy had been constructed, the user was solicited for the relative weightings that define the value or importance of each of the various objectives. Relative weights for applicable objectives were also solicited from the CAS pilots. Utility curves were produced based upon the information gleaned during the development of the problem definition and operational concept. Risk-neutral utility curves, also described in Keeney, were used in the assessment of value for each of the characteristics of the hierarchy. Figure 4 shows an example of the utility values for signal detection range. The assignment of utility values and the performance, physical, and environmental element utility curves were based upon user requirements.

The objective hierarchy was continually updated throughout the FMD systems engineering process as candidate technologies matured and were tested. It served as the primary decision-making tool for initial candidate selection, as well as the subsequent testing and evaluation to designate candidates for transition to full development.

DEVELOP VALIDATION/VERIFICATION CRITERIA

The next step involved developing the criteria necessary to verify the potential solutions against the derived requirements, and further validating them against the user need or mission requirement. The problem statement, operational concept, and requirements set served as the sources for these criteria.

The basic approach involved breaking the problem down into critical operational issues (COI). Measures of effectiveness (MOE) were then developed for each COI to help evaluate whether or not a particular candidate was able to resolve the issue. MOEs were then broken down into specific measures of performance (MOP) that could be measured to verify the candidate design (Roedler & Jones, 2005; Sproles, 2000; Sproles, 2001). Great care was taken to state these criteria in solution-independent terms such that the evaluation did not suggest or favor a particular type of solution.

CANDIDATE IDENTIFICATION AND DEVELOPMENT

The process of identifying candidate technologies began with a meeting of the stakeholders to present the critical need and the resulting operational problem. The technology experts were then given the operational concept and the requirements for the FMD, and asked to identify novel technology candidates to solve the operational problem. An initial set of 15 candidate technologies resulted.

This initial set of candidates was evaluated for feasibility using the objectives hierarchy. This initial evaluation helped to eliminate non-viable candidates. Based upon this evaluation, the initial set of 15 was pared down to 10 promising candidates. Over approximately 3 months, the technology experts worked in parallel to further research and develop their respective ideas for solving the problem.

LAB PROTOTYPE TESTING

Many of the decisions to this point had been made based upon predictions, analytical calculations, and bench tests—analyzing only portions of the device without testing full functionality. It was, therefore, necessary to verify the prototypes through lab testing—testing the full functionality of the device without subjecting it to a realistic operational environment. Since the prototypes were completed at different times, lab testing occurred throughout the development period rather than during a specific test period.

To proceed to the field demonstration, prototypes were required to have been successfully verified against the requirements via the lab testing. The results of the lab tests were fed back into the objectives hierarchy, and the candidate technologies were again evaluated against the objectives. As a result of the verification process, eight prototypes were selected to proceed to field demonstration.

OPERATIONAL PROTOTYPE FIELD DEMONSTRATION

To properly scope the demonstration, the team developed and coordinated a test plan, which outlined the roles and responsibilities of each participant and the major test objectives. Test and Evaluation Management guidance is well documented (DAU, 2005). The test objectives were derived from the user requirements and MOPs discussed previously. In addition, aircraft flight profile descriptions were developed, and a prioritized test point matrix was created. Finally, data requirements were documented to enable post-flight analysis of prototype performance.

The candidate prototypes were taken to the Nellis Air Force Base test range for the field demonstration. The evaluations were conducted by Air Force operational test agencies representing both user communities: the JTAC ground controllers and the combat aircrews.

Evaluation of Results

The team collected and reviewed the recorded data from the aircraft to determine the maximum detection for each device as well as to evaluate the quality of the detection display as seen from the aircraft. JTAC usability

OVERALL, THE FMD PROJECT SUCCESSFULLY APPLIED SYSTEMS ENGINEERING TO TAKE A CRITICAL USER NEED AND RAPIDLY PRODUCE VIABLE PROTOTYPES THAT COULD BE TRANSITIONED TO PRODUCTION.

assessments and aircrew comments were also gathered and reviewed in order to evaluate the performance of the prototype devices. While not a quantitative measure, the user assessments of the prototypes at this early stage were deemed critical as they would provide the direction for the next phase of development—producing the FMD. That is, once the basic technology is proven, it must still be designed to meet users' expectations for form, fit, and function. With this in mind, a review was conducted on the user assessments of each device, noting favorable characteristics as well as highlighting key areas of concern to be addressed in the next iterations of the development process.

PRIORITIZATION AND SELECTION OF OPTIONS

The results of the field demonstration were fed back into the objective hierarchy. Coupling the updated ranking from the objective hierarchy analysis with engineering judgment and qualitative user feedback, the team selected one candidate technology that met all of the objectives and held the greatest promise of being developed into a system capable of meeting the needs of the user.

Overall, the FMD project successfully applied systems engineering to take a critical user need and rapidly produce viable prototypes that could be transitioned to production. During the course of the efforts, the systems engineers gained valuable insight into the application of systems engineering to rapid prototyping. The remainder of the article focuses on key observations.

Key Observations and Results

In this section, key observations are made about the FMD project. In particular, each section presents a lesson learned and briefly describes the impact the finding had on the project.

UNDERSTANDING KEY CONSTRAINTS

Observation: Explicitly stating and understanding key constraints helped guide team decision making and brought clarity to choices.

Several key constraints were established at the beginning of the project. By stating the constraints explicitly from the outset, the entire team was focused on the same goals. This shared understanding guided decision making throughout the project. In particular, it made the choice between alternatives relatively clear when conducting trade-offs and candidate evaluations.

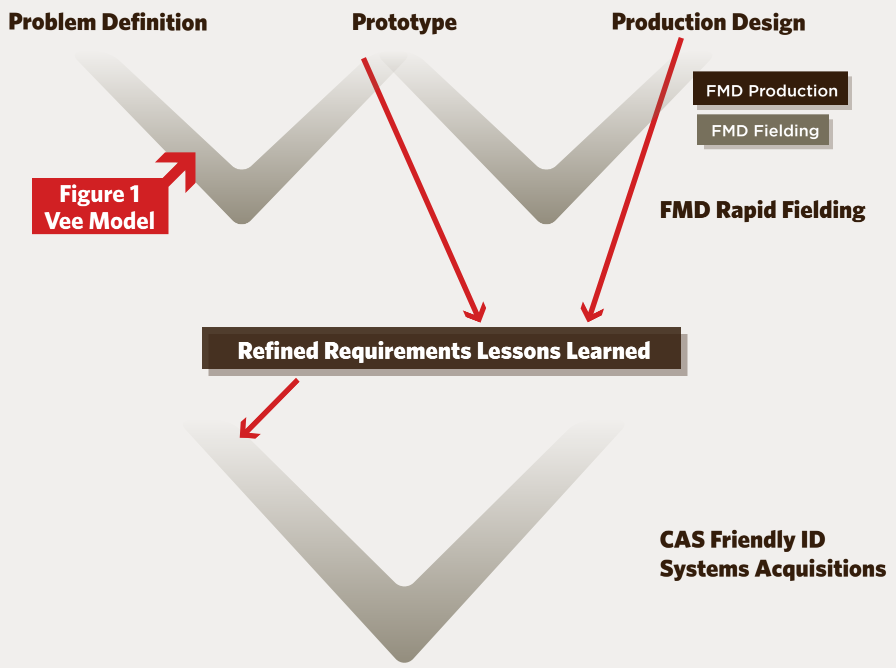
UNDERSTANDING THE LARGER CONTEXT

Observation: An understanding of the larger context helped in developing a tailored systems engineering model and provided a long-term framework for the project.

Part of tailoring the systems engineering approach involved understanding the bigger context in which this specific rapid prototyping effort fit. The programmatic boundary helped communicate scope to all the stakeholders, and helped in day-to-day systems engineering management. Figure 5 places the modified Vee model of Figure 1 into the larger context of a longer-term development fielding of future CAS systems acquisitions. In this context, the rapid prototyping Vee model represents the first increment of the FMD rapid fielding effort. This can also be viewed as the first spiral in the context of the systems engineering spiral model as shown in Figure 6. This understanding helped to modify the classic Vee model to one in which the end state was a demonstrated and validated FMD prototype. This prototype then provided both the input to the next spiral—FMD production design—as well as a refined and validated set of user requirements that can serve as important inputs for future CAS systems acquisitions.

In the spiral development context (Boehm & Hansen, 2001), FMD production design continues the spiral, resulting in a production-ready design to "fill the gap" in capability. After user evaluation and acceptance of the production design, the FMD production and fielding spiral ensues. A formal systems acquisition program for an advanced FMD was envisioned as the next spiral.

FIGURE 5. FRIENDLY MARKING DEVICE (FMD) ACQUISITION CONTEXT



BORROWING FROM OTHER DISCIPLINES

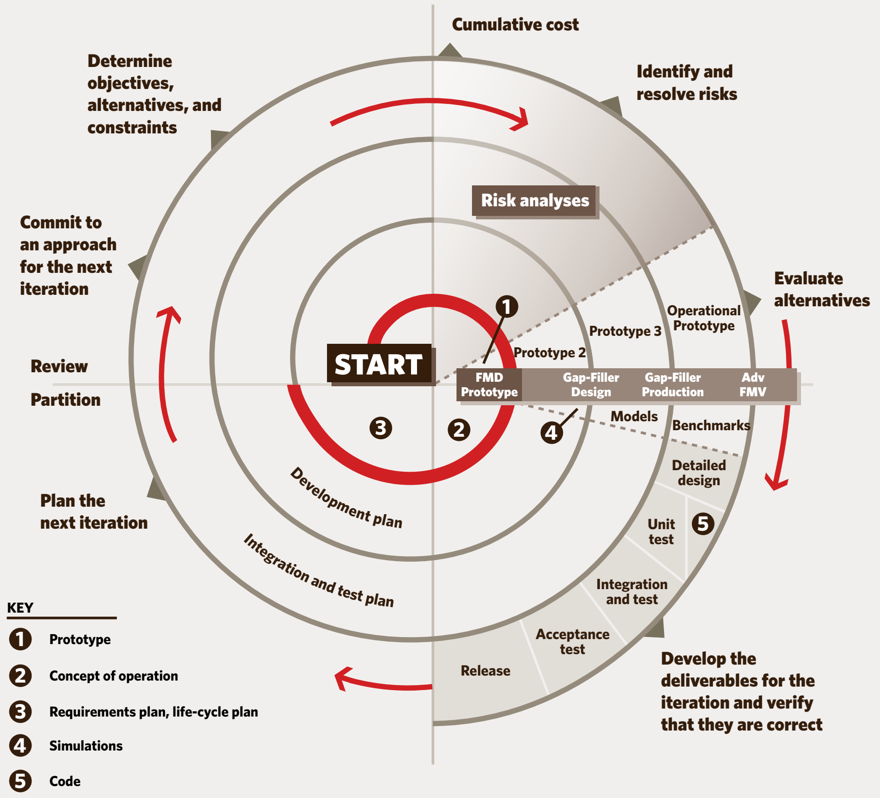
Observation: Proven techniques from software engineering were applicable in a rapid hardware prototyping effort.

The field of software engineering has, through many years of evolution, developed a very elegant approach to tame the complexity and constant change of modern software development. Whereas the waterfall approach (Royce, 1970) treated the requirements definition, design, and testing as distinct, sequential steps, modern approaches such as the Rational Unified Process (RUP) (Krutchen, 2000) emphasize evolutionary development in iterations. The FMD project applied key tenets from the RUP to the rapid development of hardware prototypes.

The sequential waterfall approach presumes that the requirements for the system can be known with a high degree of certainty from the outset and that those requirements remain relatively static during the development process. In a rapid prototyping effort, this is not very likely to be the case, particularly when the user may not know what is within the realm of the possible given the current state of the technology and the key constraining factors.

The RUP, in contrast, makes no such presumption and relies on short development steps with rapid feedback to adapt the design as requirements are clarified. The FMD project resembled the RUP in that it included an

FIGURE 6. FRIENDLY MARKING DEVICE (FMD) IN SPIRAL CONTEXT



initial exploratory phase much like an inception iteration. This phase lasted approximately 4 weeks. It included the initial meetings with the user and the entire project team. Accomplishments included creating the operational concept (vision), collecting the user's initial requirements, and defining the scope of the project. In addition, the initial technology exploration was used to check the feasibility of the novel technology ideas. Based upon initial design ideas and performance estimations, the user was able to refine the requirements and help eliminate some technology candidates because of their size, weight, or power consumption. The result was the initial list of ten candidates.

The rest of the project (as of this writing) was much like the elaboration phase of the RUP. The ten initial candidates were built into functioning prototypes. As the designers completed various phases of their fabrication work, more was learned about each of the candidates. This new knowledge was rapidly fed back into the process to further refine requirements and guide the project.

Timeboxing was also effective for the FMD project. Two candidate technologies were not mature enough to proceed to the field demonstration. Rather than slip the date, those candidates were excluded from the field demonstration with the intent to continue their development and take them to the field during a later iteration. In the interim, feedback from poor field results for candidates with similar technology (i.e., employing a similar type of emitter) showed that one of the immature candidates would not be a viable solution. That candidate was eliminated, saving both time and money.

SELECTING AND USING TOOLS

Observation: Selection of tools suited to the tailored systems engineering approach facilitated the decision-making process.

In making any decision, the development of a value model enables the systematic identification and application of user value to multiple attributes of a decision. The FMD rapid development environment required a decision tool that effectively used the limited candidate attribute information, preserved design-independent solutions, did not impose a large analytical overhead, and effectively identified the most viable alternatives.

Within the framework of the objectives hierarchy, a "living" multi-attribute decision tool was created by revisiting the phases as new and refined information was obtained. In this way, any new information, such as better performance estimates or actual test results, was quickly fed back into the objectives hierarchy to give a new snapshot of the solution space in terms of the stakeholders' objectives.

Buede (2000) discusses how the use of objectives hierarchy can be used throughout the systems design life cycle to support trade studies. Another somewhat unique application of the tool was that the objectives hierarchy was used not only throughout the design process (down the left side of the Vee model), but also as an analysis tool during the prototype evaluation process (up the right side of the Vee model) as well. The objectives hierarchy provided a mechanism to integrate actual prototype test data with long-term rapid production unit attributes such as projected weight, dimensions, etc., into a single, scoreable measure to compare alternatives. Doing so ensured that important production and usability issues were considered (via estimates and predictions) in the final candidate selection.

DEVELOPING IN PARALLEL

Observation: Parallel development helped reduce the overall risk of the project.

Managing risk is part of any project. Rapid prototyping is, arguably, itself a form of risk management in that the aim is to explore a solution space. However, in the case of the FMD project, the rapid prototyping attempted to respond to a critical operational need. In this light, there was significant incentive to ensure that some solution was identified that would be acceptable to the user.

From the outset of the project, the team sought to reduce the risk that no acceptable solution would be found. A classic risk mitigation technique when dealing with innovative and often immature technology is to pursue multiple parallel paths towards the same goal. This approach was used on the FMD project. At the initial evaluation, rather than selecting a single candidate to build and test, the team attempted to prototype all of the candidates that were predicted to meet the user need based upon the estimates and performance calculations supplied for the first iteration of the objectives hierarchy.

Another way that the parallelism helped the effort was that lessons learned by one of the parallel tracks could be fed back into the rest of the tracks to help guide and refine the remaining work. For example, early lab tests showed that modulation was especially helpful in making a signal more discernible to the observer. This information was then incorporated into the remaining designs to help further reduce risk.

MAINTAINING RIGOR IN A RAPID REACTION PROJECT

Observation: A development effort can be responsive to critical operational needs while maintaining the rigor of systems engineering.

Organizations often have very formalized and standardized systems engineering processes for product development. Within the DoD, the systems engineering process is often associated with a series of documentation requirements (formal plans, requirements, etc.) flowing through a rather large management and oversight function, coupled with a very directive series of formal reviews (DAU, 2001; Department of Defense, 1993). However, the underlying principles of systems engineering are present in the DoD process (DeFoe, 1993). When the overhead of the standard formal review and documentation requirements is reduced, a very realistic approach to conducting rapid and innovative development is generated. In fact, a common misperception is that the DoD imposes a specific systems engineering process. Rather, the *Defense Acquisition Guidebook* outlines standard industry systems engineering models and emphasizes that "models usually contain guidance for tailoring, which is best done in conjunction with a risk assessment on the program that leads the program manager to determine which specific processes and activities are vital to the program" (DAU, 2009, p. 12).

Based upon the results of the FMD project, the conclusion is drawn that by effectively tailoring the application of classic systems engineering methodologies to the problem at hand, a development effort can be responsive to critical operational needs while maintaining the rigor of systems engineering.

HEURISTICS DISCUSSION

Rather than attempting to provide a recipe for tailoring the application of systems engineering to a rapid prototyping effort, this section presents the lessons learned during the FMD project in the form of heuristics that can help guide similar efforts in the future (Maier & Rechtin, 2002).

A CUSTOM APPLICATION

Heuristic: Tailor the application of classic systems engineering practices to the specific problem at hand.

There is not a single, approved way to apply systems engineering to a given type of project. Each critical user need or problem is unique. While similarities may exist across any set of problems, each exists in a slightly different context and has its own set of challenges. Therefore, it is incumbent upon the systems engineers to examine these discriminating factors and apply systems engineering accordingly to arrive at a suitable approach. In particular, the systems engineer: must understand the larger context within which the current project resides; should look for similarities in and borrow from other projects and disciplines; and should select the appropriate tools for the job.

KEEPING THE FEEDBACK LOOP OPEN AND RAPID PROVED KEY TO THE DECISION PROCESS.

Despite the fact that each project is unique, lessons learned on similar projects and in other disciplines may prove useful. The FMD project looked to the software engineering discipline for lessons learned and for techniques to employ in developing prototypes where time is short and requirements are not fully known or understood. Keeping the feedback loop open and rapid proved key to the decision process.

Having the right tool for the job often makes a world of difference in the effectiveness of the effort. The FMD project needed a decision tool that could take the rapid feedback and continually provide an up-to-date snapshot of the solution space. The objectives hierarchy was well suited to this task. As test results came in and were entered into the tool, a new snapshot of the solution space allowed the team to continue to pursue promising technologies and drop the ones that did not perform well.

THE TEAM INTEGRATOR

Heuristic: Systems engineers can integrate the team by being the hub of a collaborative process.

When a need is critical and time does not permit the formation of a formal team, groups may come together in an ad hoc fashion to respond. The systems engineers can help to integrate the team's efforts by creating a collaborative process and serving as the hub. This role may include responsibilities such as creating or setting up collaboration tools and serving as the repository for information. In short, the systems engineer must treat the team much like a system of systems that can be integrated into a cohesive whole.

A USEFUL RESULT

Heuristic: Manage risk aggressively, but if no solution emerges, ensure that something beneficial comes from the effort—failure is not an option.

Clearly a team would prefer to see a viable solution emerge from the rapid prototyping process. Managing the risks in the process is critical, just as it is in nearly any endeavor. However, the effort should not be considered a failure if a solution does not emerge. In exploring the solution space, considerable knowledge has been gained and requirements are better understood. All of this knowledge can be fed into future efforts, allowing them to benefit from that which has gone before. Therefore, the systems engineers must aggressively manage the risks to increase the probability that a solution will be found, but must also extract the key lessons and knowledge and feed them into future efforts.

MANAGING RISK REQUIRES KNOWING THE “BOX” IN WHICH THE PROJECT MUST OPERATE.

Managing risk requires knowing the “box” in which the project must operate. That is, the team must understand the key constraints. In so constraining the effort, the team must determine what must be given up to remain within the box. On the FMD project, not modifying aircraft eliminated a significant portion of the solution space—the price for meeting the schedule and budget. Understanding this box helped frame each decision.

Conclusions

At the beginning of the article, the question was posed: Can a development effort be responsive enough to react to critical needs while still benefiting from the rigor of systems engineering? Experience from the FMD project has shown that an effort can indeed maintain the rigor of systems engineering, yet still be nimble enough to react to critical user needs in a dynamic environment. While the approach taken for the present effort will certainly not work for every rapid prototyping effort, the key observations provide some overarching lessons to guide future efforts. The heuristics provided are intended to be a few more tools in the systems engineering toolbox to aid the practitioner in applying systems engineering to meet emerging critical operational needs in a rapid prototyping effort.

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