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MISSION ENGINEERING AND ANALYSIS: INNOVATIONS IN THE MILITARY DECISION MAKING PROCESS

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Abstract
We propose mission engineering and analysis to examine and develop viable solutions for complex issues. Systems engineering addresses technological and managerial challenges in the design and development of physical and virtual systems. The military decision making process is a recognized method to develop a mission plan. The structure of mission engineering and analysis establishes the military planning process as its backbone, while systems engineering techniques serve as the internal controls and mechanisms. Scenario methodologies, modeling and simulation, hierarchical and value-focused thinking are systems engineering tools that shape the system of interest. This paper explains our ideas for creating a robust framework for tackling multidimensional problems. Mission engineering and analysis offers a holistic view of a system's development as part of a larger system. It begins with the combat mission that the system would support and ends with the system's integration in the operational unit that would apply it to achieve the mission. The process treats the system acquisition process as a sub-system. Previous methods have seen the operational mission as a start point. We designate the *mission* and *mission plan*, which may include weapon system development, as the complete system of interest. In doing so, we seek to deliver more robust and capable military and non-military systems. A notional implementation of mission engineering and analysis to assist fledgling countries conceptualize and develop solutions for border security issues captures the ideas presented in the paper.

Keywords
Mission Engineering, Military Decision Making Process, Systems Analysis.

Introduction
The rapid growth of technology, globalization, emergent challenges in the politico-military and socio-economic dimensions demand improved, systematic, and interdisciplinary decision making processes (Brown 2003). Decision making has evolved throughout human history, solving problems that range from the simplistic to the extremely complex. Making the "right" choice in the current environment requires a hybrid methodology that can adapt to the depth and scope of many multidimensional problems. Integration of the interdisciplinary framework for decision making in systems engineering (SE) with the military decision making process (MDMP) provides a holistic approach to analysis and development of viable solutions to complex issues. Both disciplines offer a set of knowledge, methods, and techniques to explore problems as they pertain to military and non-military as well as engineering and non-engineering problem domains. Poor decisions have historically resulted in severe waste of resources, loss of lives, and long term catastrophic outcomes. The risks of poor decisions are even more prominent in today's complex environment, where former Soviet countries are committed to building, enhancing, and sustaining their defense capabilities, policies, and institutions in the post-independence era.

Assisting Emerging Nations Build Credible Defense Structures
In the late 1980s, the political, social, and economic environment in the Soviet Union was decidedly unstable. Many Soviet republics were ready to proclaim sovereignty and start building a sustainable path towards their independent future. With the eventual downfall of the Soviet Union, former Soviet republics were left to autonomously build their own national defense. Each newly independent state had to individually devise means to establish national armed

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forces, ministries and security agencies to govern military actions as well as to create related military doctrines and policies to shape strategic outcomes. Simultaneously, these countries sought ways to incorporate professional standards in educating, training, and equipping their forces. Moreover, institutionalizing best practices and integrating organizations within a country's infrastructure added extra layers of complexity.

In light of immense challenges, these countries have made headway in developing credible defense forces. However, their incremental progress in military buildup and modernization has been contingent on security cooperation and assistance provided by such key actors as the United States, European Union, Russia, and China. Consequently, these strategic partners have promoted various bilateral and multilateral security cooperation mechanisms and initiatives in support of newly independent states. For instance, in 1994 the North Atlantic Treaty Organization (NATO) created the Partnership for Peace (PfP) program to increase defense and security cooperation between NATO and non-NATO eligible countries in Eastern Europe, the Caucasus, and Central Asia (NATO, 2014).

Under the broader auspices of the PfP, geographic U.S. Combatant Commands (COCOM), together with diverse U.S. security cooperation program implementers, have provided significant assistance to partner nations through enhancement of defense governance. This support has included programs to help build effective, transparent, and accountable defense institutions to manage, sustain, and employ national defense forces. In 2006 the Department of Defense (DOD) established the Warsaw Initiative Funds' (WIF) Defense Institution Building (DIB) as one of the key programs to support a number of security cooperation activities to help partner nations. U.S. security cooperation programs provide assistance-related goals as described in the WIF program and NATO's PfP program. Additionally, each COCOM and security assistance officers based at U.S. posts in recipient countries serve to ensure that the WIF program is integrated with other sources that support of U.S. security cooperation goals (Christoff, 2011).

Security Cooperative Engagement Workshops

As partner nations advance in their DIB efforts, they seek improved, systematic, and interdisciplinary decision making practices to successfully examine the myriad of issues that they must resolve. In response, COCOMs and various U.S. implementers have coordinated their security cooperation efforts to address this increasing need. The Naval Postgraduate School's (NPS) Systems Engineering Department has executed security cooperation engagements with the Uzbekistan Military of Defense to provide greater familiarization with the MDMP, the U.S. Army's time-proven analytical technique to problem solving. Sponsored under the DIB initiative, the workshop serves as a critical venue for information sharing and illustrating best practices on resolving complex defense and security related challenges.

Uzbekistan is within the U.S. Central Command's (CENTCOM) geographic area of responsibility. Coordination among the U.S. Embassy country team, CENTCOM, and the NPS lead results in a program of instruction that focuses on relevant topics. For instance, the Uzbekistan country team learned from the prospective audience that desired an emphasis on wargames during an upcoming MDMP workshop. The NPS team adjusted to the request to deliver a workshop of greater interest and also augmented the team with members from the CENTCOM Army component. These adjustments lead to the long term intent of the engagement—arm participants from Uzbekistan's ministries and security agencies with a viable approach for analyzing and developing solutions for complex issues.

The one week workshop presents a variety of topics, including problem definition or mission analysis, modeling and simulation, wargame techniques, value model development, and analysis of alternatives, all of which are captured within the MDMP framework. In many instances, SE processes are injected to articulate the approach in the seven-step decision making method. For example, course of action (COA) development is an exercise in divergent thinking for creating many options that resolve the defined problem (Giachetti 2010). Although there are lecture periods in the program, the team of subject matter experts emphasizes application, guiding participants through each step of the MDMP in a notional conflict situation. Responses from these engagements include requests for new scenarios that reflect current national problems; this manifests that countries such as Uzbekistan recognize MDMP's utility as a strategic problem solving method. The following sections describe the Mission Engineering and Analysis (MEA) process in greater detail.

Overview of the MDMP

The deliberate planning process (DPP) is deeply ingrained in the U.S. military science. It is the doctrinal process that the U.S. military employs. It consists of five phases that culminate in an executable plan for different strategic contingencies (National Defense University, 2000). The Joint Operations Planning and Execution System (JOPES), Volumes I and II provide detailed instructions for conducting DPP (Joint Warfighting Center, 1995). The final product of the DPP is the Commander's strategic concept of the operation. Upon Joint Staff review of the concept and approval from the Chairman of the Joint Chiefs of Staff, the Commander's concept of operations is developed into a concept plan, along with supporting plans. At an operational level, organizations implement the MDMP (Hernandez, 2015).

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The Army Doctrine Reference Publication (ADRP) No. 5-0: The Operations Process explains the MDMP in detail (Department of the Army (DA), 2012b). Each of the seven steps has an analog to the SE process: Mission Receipt—Stakeholder Need, Mission Analysis—Requirements Analysis and Functional Analysis, Course of Action (COA) Development—Preliminary Design Solutions, etc. Along with the *Army Doctrine Publication (ADP) No. 5-0: The Operations Process* (DA, 2012a), the U.S. Army has a common framework from which to analyze problems and develop viable solutions and plans. Exhibit 1 shows the seven steps in MDMP.

Exhibit 1. The Seven Steps of the MDMP as Presented in *ADRP 5-0* (DA, 2012b).

Key inputs	Steps	Key outputs
• Higher headquarters' plan or order or a new mission anticipated by the commander	Step 1: **Receipt of Mission**	• Commander's initial guidance • Initial allocation of time
	Warning order	
• Higher headquarters' plan or order • Higher headquarters' knowledge and intelligence products • Knowledge products from other organizations • Design concept (if developed)	Step 2: **Mission Analysis**	• Mission statement • Initial commander's intent • Initial planning guidance • Initial CCIRs and EEFIs • Updated IPB and running estimates • Assumptions
	Warning order	
• Mission statement • Initial commander's intent, planning guidance, CCIRs, and EEFIs • Updated IPB and running estimates • Assumptions	Step 3: **Course of Action (COA) Development**	• COA statements and sketches - Tentative task organization - Broad concept of operations • Revised planning guidance • Updated assumptions
• Updated running estimates • Revised planning guidance • COA statements and sketches • Updated assumptions	Step 4: **COA Analysis (War Game)**	• Refined COAs • Potential decision points • War-game results • Initial assessment measures • Updated assumptions
• Updated running estimates • Refined COAs • Evaluation criteria • War-game results • Updated assumptions	Step 5: **COA Comparison**	• Evaluated COAs • Recommended COAs • Updated running estimates • Updated assumptions
• Updated running estimates • Evaluated COAs • Recommended COA • Updated assumptions	Step 6: **COA Approval**	• Commander-selected COA and any modifications • Refined commander's intent, CCIRs, and EEFIs • Updated assumptions
	Warning order	
• Commander-selected COA with any modifications • Refined commander's intent, CCIRs, and EEFIs • Updated assumptions	Step 7: **Orders Production**	• Approved operation plan or order

CCIR commander's critical information requirement
COA course of action
EEFI essential element of friendly information
IPB intelligence preparation of the battlefield

A Model for the Systems Engineering Process

The SE process starts with a stakeholders' stated need and ends with a final product that proposes a viable solution to the issue from which the need emerged. Exhibit 2 illustrates an adaptation of the "Vee" model representing the SE process for the development lifecycle of a system (Blanchard and Fabrycky, 2011). While there are many models for the SE process they have common activities: problem definition, decomposition of requirements and functions, development of design solutions, implementation of the selected design at component and system levels, testing or verification and validation. These general steps are not necessarily sequential. It is often the case that the steps are performed in parallel and iteratively throughout the development of the system.

A study of the Vee model quickly reveals that many of the steps corresponds with MDMP activities. Steps for COA analysis and comparison in the MDMP reinforce this point. They match the analysis of alternatives phase in the SE process. Equivalently, the implementation guidance for MDMP also stresses its iterative nature (DA, 2012b).

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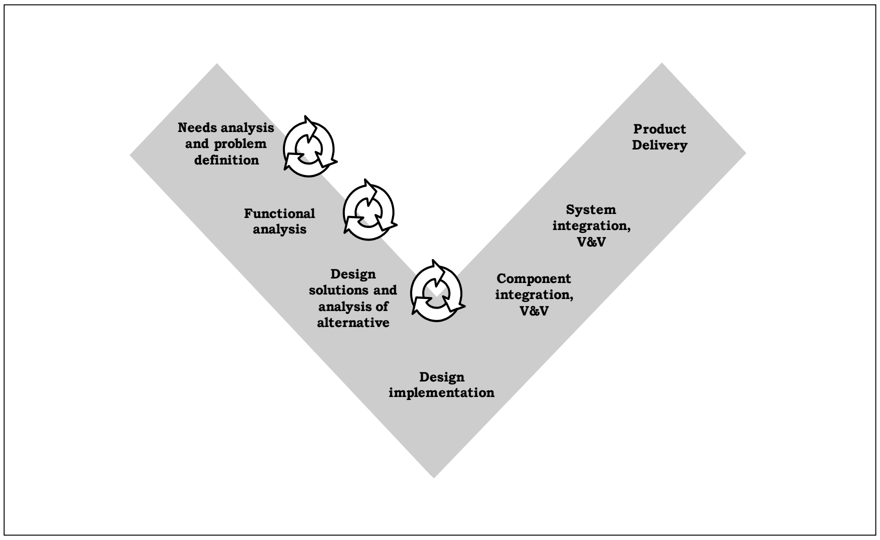
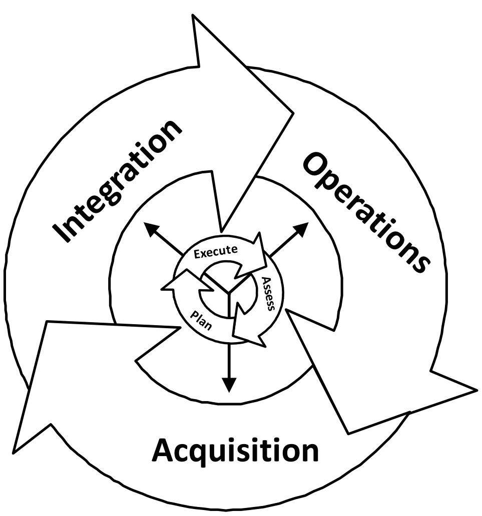
Exhibit 2. Vee Model of the Systems Engineering Process Adapted from Blanchard and Fabrycky (2011).



Introducing the MEA Process

The Office of the Deputy Assistant Secretary of Defense for Systems Engineering defines Mission Engineering (ME) as the "deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired warfighting mission effects." (Gold, 2016) This definition designates the "mission," as Wasson (2016) would describe it, as the system of interest (SoI), consisting of components represented by systems with different capabilities. The life cycle of the SoI is the duration of the mission; from the emergence of the conflict situation to mission accomplishment. The approach incorporates major processes: system acquisition, system integration into a system of systems (SoS) architecture, and actual operations that execute the mission plan. This symbiotic relationship is also iterative throughout the life cycle of the SoI. We restate Gold's (2016) ME definition by including the *mission plan* as part of the SoI and emphasizing constant analysis and assessment to inform each major process, as well as the mission planning cycle. See Exhibit 3. The following sections describe ways that the MDMP and SE can support each of these major processes. Although they are not exhaustive, the examples capture the ideas behind using these techniques to populate the MEA process.

Exhibit 3. MEA: A Refinement to the ME Model.



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Acquisition
The acquisition process begins with a material need to address an operational issue. This major process is informed with mission analysis in the MDMP, stakeholder needs analysis, problem definition, and capability engineering to define capability requirements. Systems engineering techniques populate the entirety of the acquisition process. The defense acquisition process deliberately calls out systems engineering in chapter three of the Defense Acquisition Guidebook as a critical element in the purchase of a new system (Defense Acquisition University, 2017). The Guidebook further emphasizes systems engineering when describing mature business practices; the sign of organizational maturity is the ability to understand an emerging issue and address it through material acquisition. Systems engineering proves critical in each step discussed in the Guidebook.

Each phase of procurement decisions requires review of the system requirements, testing, and analysis of system performance. Systems engineering uses an iterative approach for developing system level requirements. Ishikawa or fishbone diagrams are one of the means to develop the context of the problem and assign cause and effects relationships to fully understand the need and the purpose for developing a system solution (Blanchard and Fabrycky, 2011). Modeling and simulation based systems engineering (MSBSE) develops an acceptable representation of the system to all stakeholders (Gianni, D'Ambrogio, and Tolk, 2015). Through study of the system model in a simulated environment engineers can shape the required capabilities for the system. Computer simulation experiments also provide useful data for test and evaluation, as well as refining the operational concept for system implementation. These same concepts can inform the operations process of the MEA.

Innovations in experimentation and analysis supports acquisition processes in the system life cycle. Wargame experimentation and analysis (WEA) creates optimal stressor scenarios for operational test and evaluation (OT&E). A computerized combat simulation is the analytical backbone of WEA for exploring complex issues (Hernandez, 2017). Earlier applications of computer simulation in the system life cycle prior to OT&E phase is the basis for conducting a computer assisted wargame (CAW). The game includes human warfighters and operators to make decisions. Analysts transform the completed CAW into a closed form simulation that incorporates decision matrices to duplicate choices that warfighters made during the actual CAW. Advanced experimental designs are employed to efficiently explore the set of uncontrollable variables that are of interest to the analysis team and scenario developers. Experimentation screens out unimportant variables and locates design points with the worst outcomes. Extreme operational conditions bound the worst expected outcomes with respect to the system's performance. Results from the experiments in these stressor scenarios guide system developers to focus on specific system improvements before the operational test. We posit that a system that can achieve success in extreme conditions developed through WEA is robust enough to succeed in any other operational condition (Hernandez, 2017).

Through these methods the acquisition process produces a system (or set of systems) that can adequately address the problem. It is inherent from the evaluation phases within the acquisition process that a comprehensive approach to select the "best" system involves a process for creating feasible alternatives and relevant measures to understand trade-offs between alternatives. Value-focused thinking and value modeling are effective ways to develop useful measures upon which decisions are made (Parnell, Driscoll, and Henderson, 2011). Experimentation within MSBSE supports an optimized choice with respect to these value models.

Integration
This process involves embedding new systems and capabilities into the current SoS architecture of the organizations that will execute the mission plan. Course of action development requires creating solutions that incorporate organizations and enterprises with different capabilities. They are components in the instantiation of any COA. Component and system level integration is a critical phase of the Vee model. Wargames and scenario methodologies are prevalent in the MDMP for COA analysis and in SE for defining the operational concept and requirements. Integration is an exercise in systems thinking where a holistic analysis of the SoI and its relationship with constituent systems and operational environment is the focus. Corporations have newly discovered the value of wargames and scenario methodologies for visualizing the entirety of a problem, or proposed solutions (Gilad, 2008). As a strategic tool for maintaining corporate value, wargames assist business leaders in understanding issues and mapping prospective actions into the organization before investing resources (Oriesek and Schwarz, 2008). Visualizing potential consequences of decisions is critical to industry leaders. These activities parallel the processes that the MDMP and systems thinking methods identify for planning system integration.

Scenario methodologies include scenario planning and scenario analysis. They promote conceptual thinking and creativity. Scenarios are valuable options for solving multisided problems. Constructing current circumstances and incorporating potential actions of adversaries posit conflict situations that players must resolve. In this manner, organizations review current strategies, knowledge of the workforce, and processes. Assessments of outcomes, as

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well as decisions and activities that precede them are of great importance. Feasibility analysis in SE is a means to examine the breadth and scope of the solution space for understanding the technological approach to problems.

Enterprises that regularly deal with simultaneous crises seek the advantage that scenarios offer. Given the multifaceted problems it frequently encounters, DOD has strongly advocated scenario analysis in military planning (National Defense University, 2000). Industry has re-introduced scenarios during strategy sessions to keep pace with market volatility (Lindgren and Bandhold, 2009). These same ideas are useful throughout the integration of a system into a SoS and the conflict situation into which it was designed to operate.

Closely related to scenario methodologies are wargames. A wargame is a simulation of warfare in which opposing players (with opposing objectives) make decisions to "win." Games help answer how a specific variable affects the outcome of a battle. Variables take the form of systems, organizations, policies and activities. They, along with the conflict situation and measures that analysts are most interested in examining, define the scenario.

Of late, games have gained a resurgence in commercial and government arenas. As an intellectual exercise, wargames extend naturally into many enterprises. A wargame is a systematic approach for synchronizing resources over time and space against intelligent, aggressive opposition to achieve a desired end. Such situations occur in more places than just combat. The executive lounge, a football field, or a manufacturer's supply chain contain all the elements of a wargame.

The "mental gymnastics" involved with gaming directly relate to systems thinking. Systems thinking is a different way of studying factors that affect a given situation. Where classical analysis assumes the independence of the factors, systems thinking seeks to understand their interdependence. This evolution of game play as Gharajedaghi (2006) explains, is the most potent principle in systems thinking: the ability to see multidimensional relationships of a problem. Incorporating wargames, scenario methodologies, and systems thinking creates a robust tool set for MEA.

Operations

Operations processes include the application of all elements of national power: diplomatic, economic, informational, and military. For our purposes we focus on military operations that implement system capabilities to accomplish mission objectives. In the SE process delivery of the system for user operations includes constant analysis of system performance. In the MDMP the final product is a plan to execute the mission. The final product of MEA is a completed mission that results in success—meeting the operational objectives.

Again, there are numerous techniques incorporated in the MDMP and SE that support the operations process. The MDMP results in an operations order (or plan) to accomplish the mission. A complete concept of operations for the system is a SE requirement prior to functional analysis and decomposition that lead to creating design solutions.

Wargames to analyze COAs and the verification and validation process in SE are means to understand the level of success that a mission and a system will attain. The operational phase of a system's life cycle requires continued user assessment about the system's ability to achieved its required mission. The constant feedback refines the need for the system and guides necessary modifications (Blanchard and Fabrycky, 2011). The MDMP is a constant cycle. Refining a plan is part of every staff member's duty (DA, 2012a). When new information becomes available, or previously vague situations clarify, or higher headquarters issue new orders, the planning cycle must be reinitiated at the mission analysis step to determine how to adjust the plan. The MEA approach reflects this need for refinement to the SoI. Exhibit 4 depicts the alignment and iterative nature of the MDMP and SE that feed major MEA processes.

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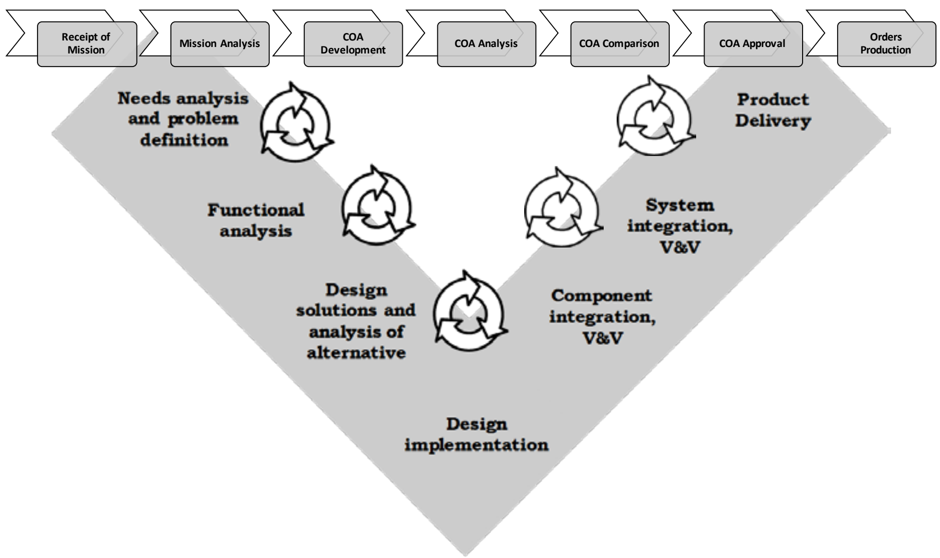
Exhibit 4. A Mapping of the MDMP onto SE Phases.



Notional Application of MEA—Border Security Issues

Application of a modified version of the MDMP to an engineering problem is relatively straightforward. In reality a meticulous implementation is closer to creating an operations plan with subsequent updating to, and execution of, an operations order. Consider the challenge for newly independent republics of detecting border intrusions by personnel. The approach to addressing this need, once identified, is directly related to the MDMP.

We must first understand the problem and the stakeholder need. This step would relate to MDMP Step 1, Receipt of the Mission. The engineering team must first determine the nature of the mission in detecting potential personnel intrusions on the border. In this particular case it is not merely an observation mission, but a network of the nation's homeland security organization with response resources to quell the intrusion. The conditions and constraints of the mission will include intrusions in an area of complex terrain and excessive background clutter for possible sensors. In addition, there will be other activities in the vicinity of the intrusions, such as planned legal border crossings, that are unrelated and will complicate detection. A feasibility analysis can illuminate possible solutions for this situation. Based on the analysis, the resultant options may be limited to passive sensors with no active signals such as those found in radar or laser illuminators. Another requirement for the system is to determine the number of intruders for the border security arm of the homeland security organization. The system must also identify intruders by category in terms of the type of equipment they use during intrusion. These are only a few of the factors that the engineering team must consider in understanding the problem definition and the effective need of the stakeholders.

Second, the mission to be accomplished by a proposed system must be analyzed in more detail through decomposition of requirements and functions. The analysis should provide enough detail to permit ideation of possible solutions. This step would actually relate to MDMP Step 2, Mission Analysis (Exhibit 1). The details required would flow from input of domain experts much as the staff conducts running estimates in the MDMP. For example, the engineering team must determine the portions of the electro-magnetic and/or acoustic spectrum that show the most promise for detecting the personnel border intrusions. In this case, detecting sensors utilizing the mid-wave infrared (MWIR) provide the ability to detect thermal signatures of the intruders with lower clutter signal from the background. Such information enables the genesis of design. Analyses of functions and timelines for the overall mission as well as for a proposed system must also be accomplished. These should render a generic mission concept as well as a set of top-level requirements that will enable the beginning of the design.

Next, possible system preliminary design solutions must be synthesized. This relates directly to MDMP Step 3, COA Development. As with the MDMP, alternative solutions are hypothesized. In this case, possible solutions stem from comparison of functional requirements with candidate technologies. These technologies must be assessed to determine if they will be viable in the time frame required. Generic subsystems or components that meet functional requirements are mapped to the different technologies. For example, a wide field of view (FOV) MWIR sensor or a scanning narrow field of view MWIR sensor may be used to initially detect the intruders as part of a generic sensing

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subsystem. There may also be several algorithm approaches to tracking the intruders in a potentially cluttered background once detection has taken place. These subsystem or component solutions may be applied in different combinations that will result in several instantiation of a system. The engineering team should develop at least three viable system alternatives for evaluation.

Fourth, the system alternatives must be evaluated in an analysis of alternatives to determine the best solution. This systems engineering step fits nicely with MDMP Step 4, Course of Action Analysis (Wargame), MDMP Step 5, COA Comparison and MDMP Step 6, COA Approval. The system alternatives are evaluated against a performance standard for accomplishing the mission. Much as wargames are used in MDMP, modeling and simulation is applied in this systems engineering evaluation step to assist in determining the best overall solution. For example, a solution with a wide FOV MWIR sensor coupled with a hand off to a narrow FOV MWIR sensor provides a higher rate of detection and other required border intruder information than that of a scanning narrow FOV MWIR sensor alone. These solutions may also be evaluated against other criteria such as cost and schedule.

Lastly, the systems engineering solution must be realized through implementation of the selected design at component and system levels as well as testing or verification and validation. This step matches most closely with MDMP Step 7, Orders Production, as well as execution of an operations order. In addition, as with the development of an operations plan, the engineering solution is revised through concept refinement and optimization. Systems engineering decisions must be documented. These include the overall architecture, integration concept, preliminary system layout and concept of operations. The border intrusion detection system, in this case, can be tightly integrated into the security organization of the nation's border security forces. Specific imagery of intruders along with real time location information is passed to those forces for use in their response.

The preceding example illustrates how the MDMP can be applied to problems requiring a systems engineering solution. In both cases a problem must be solved. For MDMP the problem is that of accomplishing an upcoming military mission. In the systems engineering case, a need is identified and addressed in a manner analogous to the MDMP. Accomplishing the "mission" of addressing an effective need is the aim of any systems engineering process model. The overall approach is scalable; it is suitable for tactical and strategic problems.

Conclusions

The MEA is a robust approach for examining complex issues and developing a holistic plan to address the problem(s). Tools for decision making throughout the SE process is well-defined. Their application to a modified version of the MDMP creates a more general methodology for developing a solution to engineering and non-engineering problems. Thus, viewing a complex issue via an MEA approach offers a more direct way to study a complex problem. In many respects the solution has a number of similarities to an operations plan, which includes supporting plans. Supporting plans in MEA may also articulate new system development and concept of operations for applying that system, as well as the application of other elements of national power that supports the SoI—plans for economic sanctions, information operations. These plans are in keeping with the major processes of the MEA. Inherent in this process is the continuing collection of information, analyses, and the subsequent need to update the mission plan. Strong relationships between the MDMP and SE processes form a natural foundation for solving complex problems. We offer MEA as a unifying approach for addressing multidimensional, strategic level problems.

Recommendations

Engagements with emerging nations should emphasize problem solving methods. Whether the problem is undertaking military operations or acquiring engineering solutions, a process with common elements greatly simplifies the ability to collaborate toward an acceptable solution. Use of the MDMP through training can readily form the basis for establishing MEA. Workshops with partner nations and within the U.S. military can help promulgate the MEA process. Systems engineering and other professional societies should establish working groups to further refine each process in the MEA and adopt best practices from the military, SE, and other engineering disciplines to develop integrated techniques and standards. The Office of the Deputy Assistant Secretary of Defense for Systems Engineering should designate MSBSE as a core element of MEA. Engineering disciplines and the DOD have increasingly leaned on modeling and simulation each passing year. The growth in computing power, development of improved experimentation methods, and new modeling techniques point to simulation models as long term tool for MEA.

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