NPS-AM-10-162

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System Dynamics Modeling for Improved Knowledge Value Assessment: A Proof-of-Concept Study

9 August 2010

by

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Prepared for: Naval Postgraduate School, Monterey, California 93943

The research presented in this report was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

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Abstract

Effective and efficient DoD acquisition programs require the analysis of a wide range of materiel alternatives. Diversity among alternatives, difficulties in selecting metrics and measuring performance, and other factors make the Analysis of Alternatives (AoA) difficult. The benefits of alternatives should be included in the AoA, but cost estimates dominate most AoA processes. Incorporating benefits into AoA is particularly difficult because of the intangible nature of many important benefits. The current work addresses the need to improve the use of benefits in AoA by building a system dynamics model of a military operation and integrating it with the Knowledge Value Added (KVA) methodology. The synergies may be able to significantly improve the accuracy of KVA estimates in the AoA process. A notional mobile weapon system was modeled and calibrated to reflect four weaponized Unmanned Aerial Vehicles (UAV). Modeling a hypothetical AoA for upgrading one of the UAV indicated that there were potentially significant synergies that could increase the number of alternatives that could be analyzed, establishing common units of benefit estimates for an AoA, improved reliability of an AoA, and improved justification of AoA results. These can improve alternative selection, thereby improving final materiel effectiveness, thereby improving the DoD acquisition processes.

Keywords: DoD acquisition programs, Alternative Diversity, Analysis of Alternatives (AoA), Knowledge Value Added (KVA), Unmanned Aerial Vehicles (UAV), alternative selection

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Acknowledgments

The authors thank the NPS Acquisition Research Program, especially RADM James Greene, for financial support and leadership.

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Dr. Tom Housel specializes in valuing intellectual capital, knowledge management, telecommunications, information technology, value-based business process reengineering, and knowledge value measurement in profit and nonprofit organizations. He is currently a tenured full professor for the Information Sciences (Systems) Department. He has conducted over 80 knowledge value added (KVA) projects within the nonprofit, Department of Defense (DoD) sector for the Army, Navy, and Marines. He has also completed over 100 KVA projects in the private sector. The results of these projects provided substantial performance improvement strategies and tactics for core processes throughout the DoD organizations and the private-sector companies. He has managed a portfolio of over $5 million worth of field studies, educational initiatives, and industry relationships.

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Table of Contents

Introduction

The U.S. defense acquisition process is initiated by the Joint Capabilities Integration and Development System (JCIDS), which is one of the three major decision support systems used in the DoD to interconnect and arrive at a new warfighting capability. The JCIDS formulates force requirements with a "top down" approach that serves as both a Joint Force integrative process and one that can also hierarchically decompose the complexities of the battle spaces and their critical mission elements. It must also be aligned with the Planning, Programming, Budgeting, and Execution System (PPBES) funding process as a way to descend from the strategic to the tactical in acquisition programs and budgets. Guidance from the current version of *Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01g* (2009, p. a-2 (8)) states,

> When a materiel solution is required by an approved ICD, the milestone decision authority (MDA) determines the scope of the subsequent analysis of alternatives (AoA), the appropriate entrance milestone, and designates the lead component(s) in a Materiel Development Decision (MDD). The purpose of the Materiel Solution Analysis phase is to assess potential materiel solutions and to satisfy the entrance criteria for the next program milestone as designated by the MDA. If the next phase per the MDA is Milestone (MS) A, then the ICD along with the results of the AoA form the basis for the MS A decision.

JCIDS uses Capability-based Assessments (CBA) to validate capability gaps; to discover solutions such as those addressed by nonmateriel-type changes to doctrine, organization, training, leadership and education, personnel, or facilities; or to pursue materiel solutions. Essential to CBA subprocesses is the knowledge of various functional warfighting Joint Capability Areas and how those communities operate within a joint paradigm. Functional Capability Boards are organized around top-tier functional areas such as Force Application, Logistics, etc.

Once needs are specifically derived in an area, and it is ascertained that they can only be addressed by new materiel, the acquisition community is still often left with either a variety of system types or technical approaches within a particular system type to fully address that capability need. An in-depth Analysis of Alternatives (AoA) helps sponsors and program managers compare options. Examples include manned or unmanned aircraft versus a missile, chemical energy versus kinetic energy kill mechanisms, etc. In the past, these have also been called Cost and Operational Effectiveness Analyses and cost-effectiveness analyses—all variants of a business case analysis.

The focus of the current work is on improving the Analysis of Alternatives (AoA) process that is used to make these major acquisition decisions. We will demonstrate the use of a system dynamics modeling approach that incorporates common units of benefits parameters using the KVA methodology and the potential improvements that might result in an AoA.

Problem Description

In typical weapon system acquisition programs, there is a point at which an AoA is conducted to select the most viable and cost-effective materiel solution so that it may be pursued into advanced development and production. Often a selection for advanced technical development among competitive system prototypes is needed, a practice that has recently become official DoD acquisition policy, but is not a new idea (USD[AT&L], 2007).

System concepts are further clarified during the Materiel Solutions Analysis phase and the accompanying AoA process. As part of this process, programs move toward several kinds of evaluative cost comparisons that formulate costs estimates across a notional lifecycle. In these early stages, programs use analogous and parametric cost-estimation techniques. Parameters of system performance and key system characteristics are selected from technical and operational inputs. Usually several Key Performance Parameters included in the Initial Capability Document are used in the AoA to quantify points of differentiation.

Simulations help address uncertainty across likely operational contingencies (Ford & Dillard, 2008, 2009a, 2009b). Balancing of programmatic and operational risks should be accounted for, but costs predominate most analyses because, for major weapon systems, they can be huge. Not only must research and development costs be considered but also production costs and, beyond that, all of the operating costs of spares, diagnostics, maintenance, tools, training manuals, etc., must be estimated. The GAO *Cost Estimation Guide* (2009) states,

> For example, 10 U.S.C. § 2434 requires an independent cost estimate before a major defense acquisition program can advance into system development and demonstration or production and deployment. The statute specifies that the full life-cycle cost—all costs of development, procurement, military construction, and operations and support, without regard to funding source or management control—must be provided to the decision maker for consideration. In other cases, a program manager might want initially to address development and procurement, with estimates of operations and

> support to follow. However, if an estimate is to support the comparative AoA, all cost elements of each alternative should be estimated to make each alternative's cost transparent in relation to the others. (p. 47)

While the emphasis is clearly on cost in these stages, operational effectiveness must also be considered because that is where benefits are realized. Current guidance does not provide a method for estimating benefits in common units. Some feel that the emphasis is disproportionately on cost without enough emphasis on benefits. The GAO's *Cost Estimation Guide* (2009) offers the following:

> AOA compares the operational effectiveness, suitability, and LCCE of alternatives that appear to satisfy established capability needs. Its major components are a CEA and cost analysis. AOAs try to identify the most promising of several conceptual alternatives; analysis and conclusions are typically used to justify initiating an acquisition program. An AOA also looks at mission threat and dependencies on other programs. When an AOA cannot quantify benefits, a CEA is more appropriate. *A CEA is conducted whenever it is unnecessary or impractical to consider the dollar value of benefits, as when various alternatives have the same annual monetary benefits. Both the AOA and CEA should address each alternative's advantages, disadvantages, associated risks, and uncertainties and how they might influence the comparison* [emphasis added]. (p. 35)

The references here to benefits are primarily in the form of cost avoidance or cost savings. Clearly, these are not equivalent to normal estimates of benefits in the business world where revenue is the primary indicator of benefit and is not derived from the denominator or cost side of the equation. Monetizing benefits as some form of cost savings or avoidance leads to a slippery slope where the only indicator of value, or numerator in a productivity equation such as return on investment (ROI), is a derivative of the denominator, i.e., cost. Such predilections inevitably lead to the lowest cost alternatives, which may not provide the highest benefits.

Research Focus

Benefits, in common units, should be included in AoA to enable higher fidelity comparisons among alternatives on the basis of value and not just cost. But how can sponsors and program managers best valuate very real and important but intangible benefits such as combat effectiveness, survivability, or national security? Lacking a credible ability to quantify such subjective or intangible benefits of the capabilities of a system type (or technical alternative) is a serious omission in any rigorous Analysis of Alternatives. The experience of Colonel Dillard, one of the authors of this report, includes several recent examples that illustrate the need for more than a conventional cost effectiveness analysis to defend a program requirement or a system parameter of technical capability. Often a particular system parameter of capability (e.g., weight, C-130 transportability, vertical take-off and landing) becomes a metric of program life and death, but with notably sparse articulation of empirical benefit to the customer or end-user.

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The Case of the Javelin Anti-Tank Weapon System

The Javelin anti-tank weapon system was, when it was conceptualized, merely named after its requirement as the Advanced Anti-Armor Weapon System–Medium (AAWS–M). In 1987–1989, the U.S. Army tested three competing technologies to fulfill the operational need for a one-man-portable anti-armor weapon system in the medium range (1,000–2,000 meter) category and to replace its aging and ineffective DRAGON weapon system. Principally, the weapon was to have the ability to defeat current and projected threat armored vehicles (including tanks); have a maximum range of at least 2,000 meters; weigh no more than 20.5 kg (with under 15.5 kg being desirable); have the ability to be fired from enclosed spaces; and have the ability to engage armored vehicles under cover or in hull defilade. The U.S. Marine Corps agreed to these requirements, promising to pay for production items, but not to fund research and development.

In August of 1986, "Proof of Principle" contracts of $30 million each were awarded to three competing contractor teams, spanning a 27-month period (the phase we now call "Technology Development") to develop the technologies and conduct a "fly-off" missile competition. Each offered the needed capability solutions with differing technologies. Ford Aerospace teamed with its partner Loral Systems, offering a laser beam–riding missile. Hughes Aircraft teamed with Boeing to offer a fiber-optic guided missile. Texas Instruments teamed with Martin-Marietta, offering an imaging infra-red (I2R) or forward looking infra-red (FLIR) missile system. Each candidate system also offered some specific operational advantages and disadvantages that were almost impossible to quantify in terms of cost:

- The Ford/Loral Laser Beam Rider required an exposed gunner and a man-in-loop throughout its rapid flight. It was the cheapest at an estimated $90,000 "cost per kill," a figure that was comprised not only of average unit production cost estimates but also of reliability and accuracy estimates. It was fairly effective in terms of potential combat utility, with diminishing probability-of-hit at increasing ranges.

- The Hughes/Boeing fiber-optic guided prototype enabled an unexposed gunner (once launched) and also required a man-in-loop throughout its slower flight. It was costlier, but less affected by range accuracy with its automatic lock-on and guidance in its terminal stage of flight—and it even offered target switching. It was also more gunner -training (learning) intensive, but could attack targets from above where their armor was thinnest.

- The FLIR prototype offered completely autonomous "fire-and-forget" flight to target after launch and was perceived as both costliest and technologically riskiest. It would have been the easiest to train soldiers to use and would have been effective to maximum ranges by means of its target acquisition sensor and guidance packages. It was an outgrowth of a 1980 initiative by the Defense Advanced Research Project Agency (DARPA) called Tank Breaker that also used "top attack" as a more effective means of armored target defeat.

1988 was a busy year for the AAWS–M industry contractors as well as for the government acquirers and program sponsors. All three candidate teams finally began building and flight-testing their missile prototypes. They were also submitting their bids to the government's Request for Proposal for the upcoming advanced development phase. On the government side, acquirers were evaluating these bids and preparing to award the 36-month Engineering and Manufacturing Development (EMD) phase contract, while sponsors were completing a Cost and Operational Effectiveness Analysis (COEA) of the three candidate AAWS–M materiel solutions. Each of the teams enjoyed generally successful missile flight test outcomes as the Proof of Principle phase ended. Each flew over a dozen missiles and achieved a target hit rate of over 60%.

The Laser Beam Rider candidate emerged as the winner of the COEA, presumably from weighted cost/efficiency factors. But in a strange twist, the Source Selection Evaluation Board (SSEB), which was deliberating concurrently, instead chose the FLIR candidate, presumably because of a bias toward "fire-and-forget." As part of a typical capability formulation process, technical constraints are deliberately avoided in requirements documents to allow and encourage a maximum range of alternative solutions to the need or capability deficiency. While time of flight and gunner survivability were not stated requirements in the AAWS–M Joint Required Operational Capability document per se, fire-and-forget nevertheless translated into greatly enhanced gunner survivability and overwhelmingly appealed to user representatives (and government developers).

The EMD contract was awarded in June 1989 to the Joint Venture team of Texas Instruments and Martin-Marietta. However, about 18 months into this program, serious technical problems doubled the expected cost of development and added about 18 more months to the originally planned 36 months to complete. This constituted a Nunn-McCurdy breach of cost and schedule thresholds, with requisite congressional notifications and formal rebaselining taking the better part of the next year to accomplish. Various technical issues plagued the program at this point, with system weight being perhaps chief among them. User representatives convened a Joint Requirements Overview Council (JROC) to reevaluate the maximum weight requirement of 45 pounds and increased the program threshold to 49.5 pounds. Clearly, the Army and Marine Corps communities wanted the emergent system and its planned capabilities. But that didn't resolve all of AAWS–M's issues.

During the months that the program teetered on the brink of termination for its technical and business issues, the director of the Office of the Secretary of Defense Office of Program Analysis and Evaluation (DPAE), as a principle member of the DAB, took the program to task, stating that if the FLIR version could not be shown able to achieve the same $90,000 cost per kill as had been estimated for the Laser Beam-Rider, then the program should be terminated and restarted, changing technologies and pursuing the less risky laser-guided version. The principal cost driver of the FLIR technology that enabled fire-and-forget was a 64x64 matrix (of heat detectors/pixels) focal plane array (FPA) to be manufactured by one of the Joint Venture partners. These tiny microchips would comprise almost 14% of the estimated average unit production cost (UPC) of the entire missile. The ability of one of the few producers in the world to manufacture them with economically sufficient yield—and to achieve their rigorous performance specifications for sensitivity—

seemed, for a while, to hold the fate of the entire program. Intense scrutiny of projected yields and production costs of these critical components would determine whether the program was feasible from this aspect alone, some believed. But the answer was somewhat ambiguous, with roughly $12,000 being the target for average UPC, given a planned buy quantity of about 70,000. The cost of the FPAs wasn't the only problem with them. But it turned out that their benefits could be described in a fairly tangible way.

The AAWS–M FPA specifications were derived from a scenario-based target list of potential threat vehicles in different environments of atmospheric temperature, humidity, obscuration, etc. When the user community saw that early developmental AAWS–M focal plane arrays were not meeting the full specifications, they convened another JROC to allow stepped, incremental achievement of target defeat scenarios over time—something we would now refer to as evolutionary growth. They stratified performance in terms of levels A, B, and C to convey degrees of target defeat capability in focal plane arrays. This was a very unusual move by sponsors -- to dissect a requirement to accommodate the pace of technological achievement.[1] This provided a qualitative assessment of what was achievable and satisfactory for system performance. Once again, the communities that needed AAWS–M's capabilities were trying to ease the path forward.

Fortunately, independent program evaluation teams also reported that FLIR technology was progressing and would be achievable within a rebaselined program. This joint position, along with wider program advocacy, curtailed the technical and business arguments and the fire-and-forget Javelin was allowed to proceed. An additional and more capable provider of FPAs was brought in and accelerated as a second source for this critical component. After difficult advanced development program challenges, AAWS–M eventually became the Javelin—and is known today

[1] This is perhaps not unlike today's emergence of an Apple iPhone® being followed soon after by release of a 3G- and 4G-capable iPhone®.

as one of our most successful combat systems. (In the end, Soldiers and Marines never had to accept B- and C-level FPA performance because the full-capable FPA technology did, in fact, emerge in time for fielding. And system weight has been held just below 49.5 pounds throughout its many years of production.)

There are many business and public policy lessons to be learned from the Javelin program. Within its long saga from initial concept to modern-day deployment and combat use are illustrations of requirements capture, early prototyping, technology readiness, modeling and simulation, economic forces of competition, acquisition strategy, decision bureaucracy, product discovery, economies of scale, etc. Perhaps the best lesson learned from the case presented here about analyzing alternatives is that a single, unstated, qualitative factor of performance (gunner survivability) ultimately drove the choice. Javelin had a requirements document with many pages of quantifiable requirements stated as measures of performance and effectiveness. But the parameter of system technology that promised the most of what was impossible to quantify became the overriding factor in the selection of alternatives. A magazine advertisement purchased by the Joint Venture shortly after their EMD contract win said it eloquently: "Fire & Forget AAWS–M: The Gunner Wins." The failure of the Javelin program to move to the final solution faster and more directly was due in large part to the insufficient articulation of benefits as part of the Analysis of Alternatives process.

Research Question

As illustrated by the Javelin program, there is a basic need for the use of a common units-of-benefit estimate in the Analysis of Alternatives process. This should lead to including common units-of-benefit estimates as well as costs in the acquisition AoAs. The problem is to develop a means to do this more effectively, given the nebulous nature of so many of the critical benefits of weapon systems. How can such a method be consistently applied to many alternatives across a wide range of operational conditions? The current research examines how KVA can be integrated with system dynamics modeling to generate defensible common units of benefit estimates that will improve the rigor of the AoA process and, thereby, improve acquisition processes.

The goals of the current work are as follows:

- Examine how military operations systems dynamics (SD) simulations can be combined with the KVA approach,
- Identify potential advantages and disadvantages of integrating military operations simulations and the KVA approach,
- Investigate the potential of exploiting the benefits from the synergy of SD and KVA to improve acquisition AoA processes, and
- Identify and describe potential implications of the integration on acquisition practice.

Due to the preliminary nature of this proof-of-concept study, precise descriptions of system operations are necessary. The focus is on the potential usefulness of integrating SD and KVA.

Introduction to Knowledge Value Analysis

In the U.S. Military context, the knowledge value added (KVA) methodology is a new way of approaching the problems of estimating the productivity (e.g., in terms of ROI) for military capabilities embedded in processes such as the CONOPS for a weapons system. In the current study, we posited several alternative CONOPS for a UAV system and used system dynamic modeling to evaluate their relative productivity. The KVA approach was used to estimate the parameters based on the system dynamic models by providing the estimates of the relative productivity (i.e., the ROI[2]) of each alternative.

In a broader context, KVA also addresses the requirements of the many Department of Defense (DoD) policies and directives previously reviewed by providing a means to generate comparable value or benefit estimates for various processes and the technologies and people that execute them. It does this by providing a common and relatively objective means to estimate the value of new technologies as required in the following literature:

- The Clinger-Cohen Act of 1996, which mandates the assessment of the cost benefits for information technology investments;
- The Government Accountability Office's *Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making* (1997), which requires that IT investments apply ROI measures;
- DoD Directive 8115.01, issued October 2005, which mandated the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments; and
- DoD Risk Management Guidance in the *Defense Acquisition Guidebook*, which requires that alternatives to the traditional cost

[2] ROI is defined as the revenue cost/cost, where revenue is defined as the price per common unit of benefit using a market comparables approach. Given that the price per common unit is a constant, precision in estimating the market comparable price, i.e., revenue, is not required.

estimation be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

KVA is a methodology that describes all organizational outputs in common units. This provides a means to compare the outputs of all assets (human, machine, information technology), regardless of the aggregated outputs produced. Thus, it provides insights about the productivity level of processes, people, and systems in terms of a ratio of common units of output produced by each asset (a measure of benefits) divided by the cost to produce the output   By capturing the value of knowledge embedded in an organization's core processes, employees, and technology, KVA identifies the actual cost and value of people, systems, or processes. Because KVA identifies every process required to produce an output and the historical costs of those processes, unit costs and unit values of outputs, processes, functions, or services are calculated. An output is defined as the end result of an organization's operations; it can be a product or service, as shown in Figure 1.

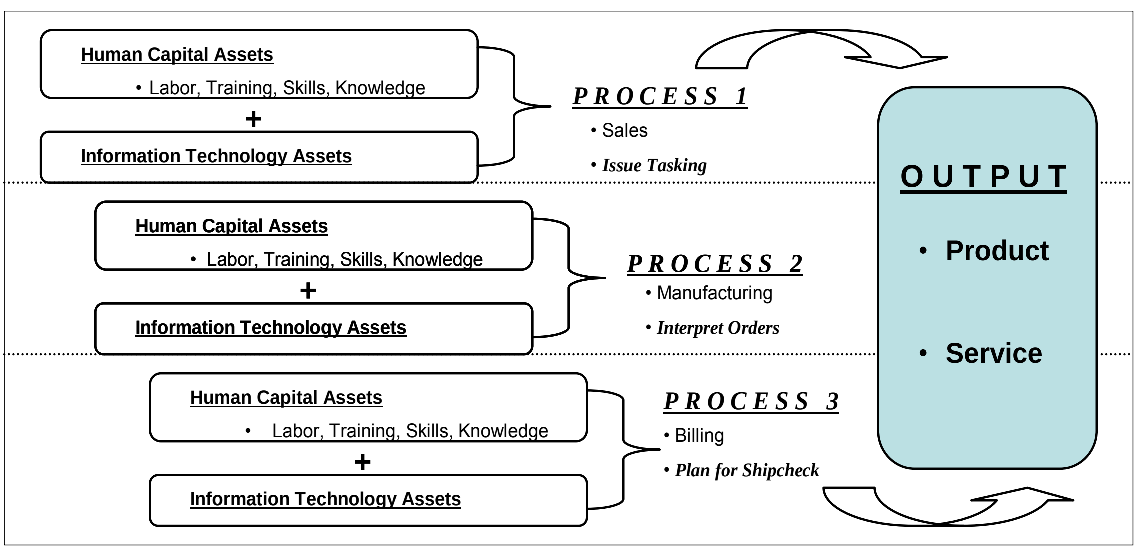

Figure 1. Measuring Output

For the purpose of the systems dynamics model developed for this study, we used KVA to describe the outputs of all the processes and subprocesses in common units. This allowed us to make their relative performance (e.g., productivity, ROIs) comparable. We used KVA to measure the value added by the human capital assets (i.e., military personnel executing the processes) and the system assets by analyzing the performances of the processes. KVA provided a means to set the systems dynamic model parameters so that the results would provide a way to compare the performance of various approaches to the system problem.

By capturing the value of knowledge embedded in systems and in use in operators of the processes, KVA identified the productivity of the system-process alternatives. Because KVA identified every process output required to produce the final aggregated output, the common unit costs and the common unit values were estimated. This allowed for the benchmarking of various systems and the processes they supported with any other similar processes across the military.

The KVA methodology has been applied in over 80 projects within the DoD, from flight scheduling applications to ship maintenance and from modernization processes to the current project analyzing several alternative approaches to the system alternatives problem. In general, the KVA methodology was used for this study because it could do the following:

- Compare alternative approaches modeled with a systems dynamics model in terms of their relative productivity;
- Allocate value and costs to common units of output;
- Measure value added by the system alternatives based on the outputs each produced; and
- Relate outputs to the cost of producing those outputs in common units.

KVA quantifies value in two key productivity metrics: Return on Knowledge (ROK) and Return on Investment (ROI). Calculations of these key metrics are shown in Table 1

Table 1. KVA Metrics

Metric	Description	Type	Calculation
Return on Knowledge (ROK)	Basic productivity, cash-flow ratio	Function or process level performance ratio	Outputs-benefits in common units/cost to produce the output
Return on Investment (ROI)	Same as ROI at the sub-corporate or process level	Traditional investment finance ratio	(Revenue-investment cost)/investment cost

Based on the tenets of complexity theory, KVA assumes that both humans and technology in organizations add value by taking inputs and changing them into outputs (measured in common units of complexity) through core processes. The amount of change an asset within a process produces can be described as a measure of value or benefit. The additional assumptions in KVA include the following:

- Describes all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) and allows historical value and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required for a single point-of-reference learner to learn to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, units of learning time are proportionate to common units of output.
- Common units of output that make it possible to compare all outputs in terms of cost per unit as well as in terms of value (e.g., price) per unit because value (e.g., revenue) can now be assigned at the suborganizational level.
- Assigns cost and revenue streams to suborganizational outputs, after which normal accounting and financial performance and profitability metrics can be applied (Housel & Kanevsky, 1995; Pavlou, Housel, Rodgers, & Jansen, 2005; Rodgers & Housel, 2006).

Describing processes in common units also permits, but does not require, market comparable data to be generated, which is particularly important for nonprofits like the U.S. Military. Using a market comparables approach, data from the commercial sector can be used to estimate price per common unit, allowing for revenue estimates of process outputs for nonprofits. This also provides a common units basis to define benefit streams regardless of the process analyzed.

KVA differs from other nonprofit ROI models because it can allow for revenue estimates, enabling the use of traditional accounting, financial performance, and profitability measures at the suborganizational level. KVA can rank processes or process alternatives by their relative ROIs. This assists decision-makers in identifying how much of the various processes or process alternatives add value.

In KVA, value is quantified in two key metrics: Return on Knowledge (ROK: revenue/cost) and ROI (revenue-investment cost/investment cost). The raw data from a KVA analysis can become the input into the ROI models and various forecasting techniques such as real options analysis, portfolio optimization, and Monte Carlo simulation. By tracking the historical volatility of price and cost per unit as well as ROI, it is possible to establish risk (as compared to uncertainty) distributions, which is important for accurately estimating the forecasted values for portfolio optimization and real options analysis.

The KVA method has been applied to numerous military core processes across the Services. The KVA research has more recently provided a means for simplifying the input values for portfolio optimization and real options analysis for DoD processes and process assets. In the current work, KVA primarily provides a methodology for comparing the relative values of processes within military operations.

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Introduction to System Dynamics

The system dynamics methodology applies a control theory perspective to the design and management of complex human systems. System dynamics combines servo-mechanism thinking with computer simulation to analyze systems. It is one of several established and successful approaches to systems analysis and design (Flood & Jackson, 1991; Jackson, 2003; Lane & Jackson, 1995). Forrester (1961) developed the methodology's philosophy, and Sterman (2000) specified the modeling process with examples and described numerous applications. The methodology has been extensively used for this purpose, including studying development projects. The system dynamics perspective focuses on how the internal structure of a system impacts system and managerial behavior and, thereby, performance over time. The approach is unique in its integrated use of stocks and flows, causal feedback, and time delays to model and explain processes, resources, information, and management policies. Stocks represent accumulations or backlogs of work, people, information, or other portions of the system that change over time. Flows represent the movement of those commodities into, between, and out of stocks. The methodology’s ability to model many diverse system components (e.g., work, people, money, value), processes (e.g., design, technology development, production, operations, quality assurance), and managerial decision-making and actions (e.g., forecasting and resource allocation) makes system dynamics useful for modeling and investigating military operations, the design of materiel, and acquisition.

When applied to acquisition programs, system dynamics has focused on how performance evolves in response to interactions among development strategy (e.g., evolutionary development versus traditional), managerial decision-making (e.g., scope developed in specific blocks), and development processes (e.g., concurrence). System dynamics is appropriate for modeling acquisition because of its ability to explicitly model critical aspects of development projects. System dynamics models of development projects are purposefully simple relative to actual practice in order to expose the relationships between causal structures and the behavior and performance that they create. Therefore, although many processes and features of system design and participants interact to determine performance, only those that describe features related to the topic of study are included. The importance of deleted features can be tested when system dynamics is used to test the ability of the model structure to explain system behavior and performance.

System dynamics has been successfully applied to a variety of development and project management issues, including rework (Cooper, 1993a, 1993b, 1993c; Cooper & Mullen, 1993), the prediction and discovery of failures in project fast-track implementation (Ford & Sterman, 2003b), poor schedule performance (Abdel-Hamid, 1988), tipping point structures in projects (Taylor & Ford, 2006, 2008), contingency management (Ford, 2002), resource allocation (Joglekar & Ford, 2005; Lee, Ford, & Joglekar, 2007), and the impacts of changes (Cooper, 1980), and concealing rework requirements on project performance (Ford & Sterman, 2003a). See Lyneis and Ford (2007) for a review of the application of system dynamics to projects and project management.

System dynamics has also been applied to military systems, including planning and strategy (Bakken & Vamraak, 2003; Duczynski, 2000; McLucas, Lyell, et al., 2006; Melhuish et al., 2009), workforce management (Bell & Liphard, 1978), technology (Bakken, 2004), command and control (Bakken & Gilljam, 2003; Bakken et al., 2004), operations (Bakken et al., 2004; Coyle & Gardiner, 1991), logistics (Watts & Wolstenholme, 1990), acquisition (Ford & Dillard, 2008, 2009a, 2009b; Bartolomei, 2001; Homer & Somers, 1988), and large system programs (Cooper, 1994; Lyneis, Cooper, & Els, 2001). Coyle (1996) provides a survey of applications of system dynamics to military issues.

Based on the literature described above and the authors' experience with system dynamics, there appears to be an opportunity to exploit the capabilities of the system dynamics methodology to make the knowledge value added approach more accurate.

Research Methodology

In the current work, KVA and system dynamics were integrated to test their ability to improve the precision of AoAs in acquisition programs. We first developed and tested a generic structure of a mobile weapon system process using the system dynamics methodology. Then we operationalized KVA value and cost estimates in the system dynamics model. The model was calibrated to reflect four extant weaponized Unmanned Aerial Vehicles (UAVs). We used one of those calibrations as the basis for employing the model in a hypothetical AoA for upgrading the UAV to address a different type of target. We analyzed simulation results to test the ability of the system dynamics model to estimate benefits streams using KVA in terms of the relative value added of the capabilities of the system.

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A Generic Model of Mobile Weapons Use

The system dynamics model has three sectors: weapons movement, target evolution, and KVA analysis. As we will describe, the model structure simulates two critical aspects of mobile weapon system operations: (1) the support and movement of the weapon and (2) target evolution from identification through confirmation of destruction.

The Weapons Movement Sector

The Weapons Movement sector of the model simulates the positions and movements of weapons (e.g., individual UAVs or Javelin gunners). Figure 2 shows the positions that weapons (generically called *assets*) can take (boxes) and the rates of their movements from one position to another (arrows between boxes). We assumed that the total number of assets remained constant, i.e., no weapons were added or lost during operations. This assumption can be relaxed when modeling a specific asset. The movement of weapons is a subprocess of operating the weapon system that adds value and imbeds learning into tools, requires learning time for operators to be capable of performing and requires processing time to accomplish. Therefore, the completion of moving weapons to the station and back to the base is an output of that subprocess and an input to the KVA analysis. The combination of the two movements "Assets arrive at station rate" and "Assets arriving as base rate" represent the accomplishment of the vehicle movement subprocess.

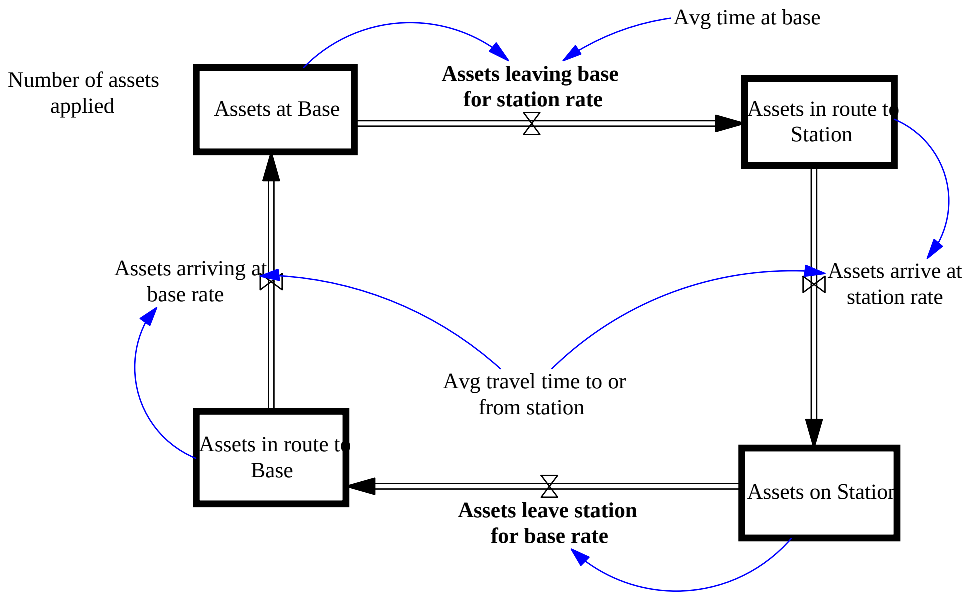

Figure 2. Positions and Movement of Weapons During Operations

Each rate in the weapons sector describes the average movement of the weapons in the accumulation that precedes the rate. Each rate is defined with the number of weapons preparing for that rate (to leave base or station) or event (to arrive at station or base) and the average time spent by a weapon in the preceding accumulation. For example, the (average) "Assets leaving base for station" rate is equal to the number of assets at the base divided by the average time that a weapon spends at the base between trips to the station. This formulation increases the average departure rate with more weapons at the base and decreases the average departure rate if weapons stay at the base longer. The average time at the base is characteristic of particular assets and can generate different behaviors and performances across weapons and configurations.

The Target Evolution Sector

The Target Evolution sector of the model simulates the development of targets through five subprocesses of system operations:

1. Acquire target—includes detection, recognition, location, classification (identification), and confirmation (Global Security, 2010).
2. Fire support coordination—allocates targets to weapons by a group of people that have access to information about the battlefield situation and about doctrine, major systems, significant capabilities and limitations, and often their tactics, techniques, and procedures (TTP) (Williams, 2001).
3. Fire mission development—prepares specific instructions and target information for transmission to the weapons team and to the weapon (e.g., target location coordinates).
4. Engage target—weapons operators (e.g., pilots for UAV) maneuver the weapon within striking distance of the target, enter the target coordinates, and launch munitions.
5. Battlefield assessment—often the same asset as was used for target acquisition is used to evaluate the success of engagement in destroying the target.

In the model, targets evolve through these stages in an "aging chain" structure of sequential accumulations (backlogs + work in progress, referred to here as backlogs) and (sub)processes that drain those backlogs and contribute to the backlog of the next downstream subprocess. Figure 3 shows the conditions of targets (boxes) and the rates of their movements from one condition to another (arrows between boxes) due to subprocesses. The movements "Acquire target completion rate," "Fire support coordination to asset," "Fire mission completion rate," "Engage target," and "Battlefield assessment rate" are subprocesses that add value, imbed learning in tools, require learning time for operators to be capable of performing and require processing time to complete. Therefore, they are each outputs of those subprocesses and inputs to the KVA analysis.

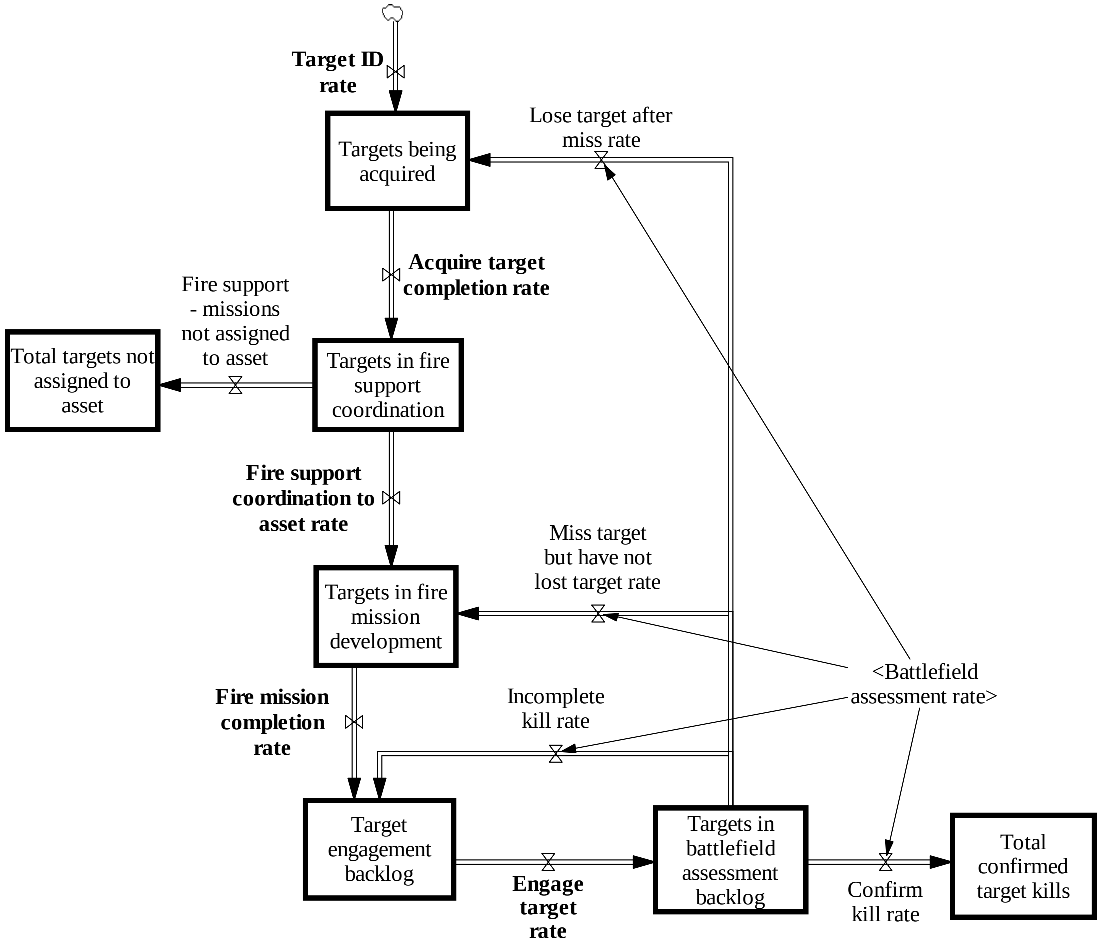

Figure 3. Accumulations and Movements of Targets in Weapon System Operations

In addition to the primary flows of targets through the subprocesses, the target sector models three common causes of mission failure: (1) hitting the target but failing to destroy it, (2) missing the target, and (3) missing the target and losing the location information needed to engage the target again (e.g., because the target moved). Each cause moves the target to a different condition in the target aging chain. Hitting the target but failing to destroy it (e.g., a hardened target) requires reengagement, but often no additional targeting information. After Battlefield assessment, these targets are returned to the Target engagement backlog. Missing the target (e.g., a small target) requires that the fire mission be developed again to re-aim the weapon prior to reengagement. Therefore, these targets are returned to the Targets in fire mission development backlog after Battlefield assessment. Losing the target (e.g., a fast-moving vehicle) requires that the target be reacquired. Therefore, these targets are returned to the Targets being acquired backlog after Battlefield assessment.

In a manner similar to the modeling of the movement of weapons, the rates in the target sector describe the average movement of targets between backlogs. The primary rates in the aging chain are defined by the number of targets in the backlogs of the subprocess and the average time required to perform the subprocess. The average time required to perform the subprocess is characteristic of particular subprocesses (e.g., different engagement durations for different weapons) and can generate different behavior and performance across weapons and configurations. When two or more flows drain a backlog (Targets in fire support coordination and Battlefield assessment backlog), the total outflow is split between the flows using a percent that leaves the stock through each outflow. The return flows are each a fraction of the Battlefield assessment rate. Those fractions are based on the ability of the weapon to successfully destroy, hit, and not lose targets. Therefore, like in practice, different weapon alternatives (e.g., range, payload, dash speed) impact mission success. The Using System Dynamics and KVA to Improve Analysis of Alternatives section of this report describes how these features of the model were used to describe operational scenarios and weapon configurations. The fractions of the Battlefield assessment rate that was returned to the engagement backlog due to being hit but not destroyed, was missed and returned to the mission development backlog, or was lost and returned to the target acquisition backlog are described with the probability of destruction if the target is hit with the ordinance (p(kill if hit) or p(kill)), the probability of the weapon hitting the target with ordinance (p(hit)), and the probability of not losing the target if it is missed with the ordinance (p(not lose)), respectively.[3] These probabilities are determined by comparing the ability of a weapon to successfully destroy, hit, and not lose targets to the characteristics of the target. More specifically, the probability of kill is modeled with the weapon's payload compared to the lethal payload (i.e., ordinance size required to kill); probability of hit is modeled with the weapon's dash speed compared to the target's speed; and the probability of not losing the target is modeled with the weapon's range compared to the target's distance from the base. Therefore,

p(kill) = f_k(Payload / Lethal payload)

p(hit) = f_h(Dash speed / Target speed)

p(not lose) = f_{nl}(Range / Target distance from base)

where,
p(kill): probability of destruction if the target is hit with the ordinance
p(hit): probability of the weapon hitting the target with ordinance
p(not lose): probability of not losing the target if it is missed with the ordinance

The three functions that estimate the probabilities based on the ratios are assumed to be simple but realistic relations that include the entire range of possible conditions.[4] The function relating the Payload/Lethal payload ratio to the probability of kill is assumed to increase linearly from p(kill)=0 when the ratio is zero (i.e., no payload prevents any chance of target destruction) to p(kill)=100% when the ratio is greater than or equal to 1 (i.e., if the payload exceeds the lethal payload, the target is assumed to be destroyed if it is hit). The function relating the Dash speed/Target speed ratio to the probability of the weapon hitting the target with ordinance assumes that the vehicle will "chase" a moving target and that the faster the vehicle is, the closer it can get to the target before releasing ordinance—increasing the

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[3] The probability of not losing a target is used instead of the probability of losing a target to retain a "bigger is better" standard for all three measures and, therefore, to facilitate intuitive understanding of the model.

[4] These functions can be described more accurately with additional weapon testing information.

likelihood of hitting the target with the ordinance. However, there is always some possibility of missing a target, even if the vehicle is faster than the target and, therefore, close to the target. The function is assumed to have an elongated *S* shape from p(hit)=0 when the ratio is zero (i.e., no Dash speed prevents hitting the target) to p(hit)=90% when the ratio is greater than or equal to three (i.e., high likelihood of hit if the weapon speed far exceeds target speed.[5] The function relating the Range/Target distance from base ratio to the probability of not losing the target if it is missed with the ordinance assumes that the vehicle will move toward the target but that the target may also move, sometimes closer to the vehicle and sometimes away from it. When the target moves away from the vehicle, it may move out of the vehicle's range, causing the vehicle to lose the target. The function is assumed to have a stretched out *S* shape from p(not lose)=0 when the ratio is zero (i.e., no weapon range causes the vehicle to always lose the target) to p(not lose)=95% when the ratio is greater than or equal to 1.8, reflecting some chance of losing the target even if it is well within the vehicle's range.

The KVA Sector

The KVA metrics were fully operationalized within the system dynamics model. The KVA sector uses operations information from the weapons and targets sectors of the model and characteristic descriptors of weapons to generate relative value metrics for each subprocess (including weapons capability outputs) of the UAV operations. KVA generates a productivity ratio that reflects output/input. If monetized, this ratio can be a traditional benefit-cost ratio (e.g., ROI if benefits are monetized as a form of revenue surrogate). Other measures of benefits and costs can also be used—as long as there are common units in the numerator (benefits) and all the cost units of all the contributors to the denominator are the same (as is most often the case because costs are almost always monetized)—so they can each

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[5] The assumed function relating the Dash Speed/Target Speed to the probability of hitting the target is probably lower than current experience, but is used to reflect the change in targets described in the Using System Dynamics and KVA to Improve Analysis of Alternatives section of this report.

be aggregated. At each point in time, each subprocess's productivity is the benefits it has generated divided by the costs of generating those benefits (i.e., output/input).The model includes both monetized and time-based KVA metrics.

Monetized KVA Metrics

When monetized, the numerator (benefits) for each subprocess is the accumulation across operations of a fraction of the value added by one complete operation (e.g., in this case it would be the monetary value of the destruction of a target). The fraction allocated to each subprocess is directly proportional to the Learning time required to produce the outputs of the subprocess, in common units of learning time. Learning time captures the benefits derived from human processing (e.g., flying the vehicle), automated processes (e.g., takeoffs and landings), and (importantly) technologies integrated into the weapon. The denominator of monetized subprocess KVA productivities is the accumulation across operations of the costs incurred to perform the subprocess. How these were modeled is described next.

The benefit generated by a weapon system is the destruction of targets. That benefit can be monetized with an estimate of the value (in monetary terms) of the destruction of a typical or average target. This value can be estimated with the cost that the government would have to pay a private entity to perform the same task without the use of the weapon system (e.g., using a land-based operation instead of an aircraft or missile). The benefits generated by each subprocess are a fraction of the total benefits that the operation has accumulated so far. That fraction is modeled as being directly proportional to the learning times (reflecting complexity as a common units measure of value added) of the subprocesses. Those total benefits of a subprocess are the accumulation over time of the product of the subprocess's portion of the benefits for a single target and the rate at which the subprocess is being performed. Based on this, a set of equations for estimating the benefits of a single subprocess are as follows:

Unit subprocess benefit fraction = Subprocess learning time /
Total of all subprocess learning times

Unit subprocess benefit = Unit subprocess benefit fraction *
Unit benefit for entire process

Rate of subprocess generating revenue = Subprocess processing rate *
Unit subprocess benefit

Subprocess benefits generated to date = ∑(Rate of subprocess generating benefits) * dt

where,
dt: timestep, the period over which the argument is integrated

The denominator of KVA subprocess productivity ratios represents subprocess costs. The cost to date at any time is modeled as the product of the time required to perform the subprocess and the average hourly cost of performing the subprocess. The total time spent performing a subprocess at any given time is the product of the average time required for the subprocess and the number of performances of the subprocess. Therefore, a set of equations for estimating the costs of a single subprocess in each time period are as follows:

Rate of spending time on subprocess performance =
Subprocess performance rate *
time required to perform the subprocess

Subprocess work time spent to date =
∑ (Rate of spending time on subprocess performance) * dt

Subprocess processing time generated to date =
Subprocess work time spent to date * Hourly performance cost

In each time period, subprocess benefits and costs are combined into subprocess KVA productivity ratios.

Subprocess productivity = Subprocess benefits generated to date /
Subprocess processing time generated to date

The calculation of monetary KVA metrics has been incorporated into the system dynamics model. However, the modelers decided that the current model would be simpler to interpret by using the non-monetized common units of output (as described in terms of the units of time it would take the average person to learn how to produce the outputs) as the numerator. This results in a standard definition of productivity (output/input).

Time-Based KVA Metrics

Calculating the learning time–based KVA metrics applies the same approach as the monetized metrics, but uses Learning Time to quantify benefits and Touch Time to quantify costs instead of money. One of several ways to quantify a subprocess's Learning Time is to estimate the average time required for a common point-of-reference learner to be trained and become competent in performing the subprocess. Each subprocess is assigned a unit learning time that reflects the relative (compared to other subprocesses) complexity of the subprocess. Each subprocess is also assigned a Unit Touch Time that reflects the relative (compared to other subprocesses) effort required to perform the subprocess. These are aggregated over many operations and compared in order to generate a subprocess's productivity ratio. The equations for modeling time-based KVA metrics for a subprocess are as follows:

Subprocess learning Time accumulated to date =
$\sum$ (Rate of subprocess operation * Subprocess unit learning time) * dt

Subprocess touch time accumulated to date =
$\sum$ (Rate of subprocess operation * Subprocess unit touch time * dt

Subprocess Productivity = Subprocess learning time accumulated to date / Subprocess touch time accumulated to date

Learning Times and Touch Times are also aggregated across subprocesses in order to estimate the productivity of the entire operation. This allows the comparison of different asset configurations (alternatives).

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A Brief Introduction to Weaponized Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs) have a long history, dating from their use as targeting drones in the 1920s (Jones, 1997). They have evolved into reconnaissance assets, valuable particularly where air space is considered too dangerous for manned aircraft. Other advantages, such as the ability to remain on station for extended periods of time, reduced mission costs, and access to space denied to manned aircraft, have been exploited in more recent UAVs. In the DoD, UAVs are divided into three classes:

- Close Range UAVs (UAV-CR) that operate within a range of about 50 kilometers;
- Short Range UAVs (UAV-SR) with 8-10–hour flight durations, a range of 200 kilometers, and the ability to communicate through a datalink; and
- Endurance UAVs (UAV-E) with at least 24-hour flight durations and the ability to perform multiple missions simultaneously.

Weaponized UAVs were developed and used in the Vietnam War. The Navy's DASH UAV helicopter carried two 250-pound torpedoes that were used to destroy North Vietmanese supply barges in the Mekong Delta waterways after detection by the vehicle's television camera (Global Security, 2010). However, technical and other limitations prevented the further operationalization of weaponized UAVs for several decades. Several weaponized UAVs are now operational, including the MQ-1 Predator, MQ-9 Reaper, and Sky Warrior, with the last two being decedents of the Predator. Other weaponized UAVs are under development, including the X-45B (also known as the Unmanned Combat Air System–Navy or UCAS–N) by Northrop Grumman (Figure 4) that will include aircraft carrier suitability (Cayas, 2007), and is being tested on the USS Abraham Lincoln (Marks, 2010).

Figure 4. An Artist's Rendering of an X-47B

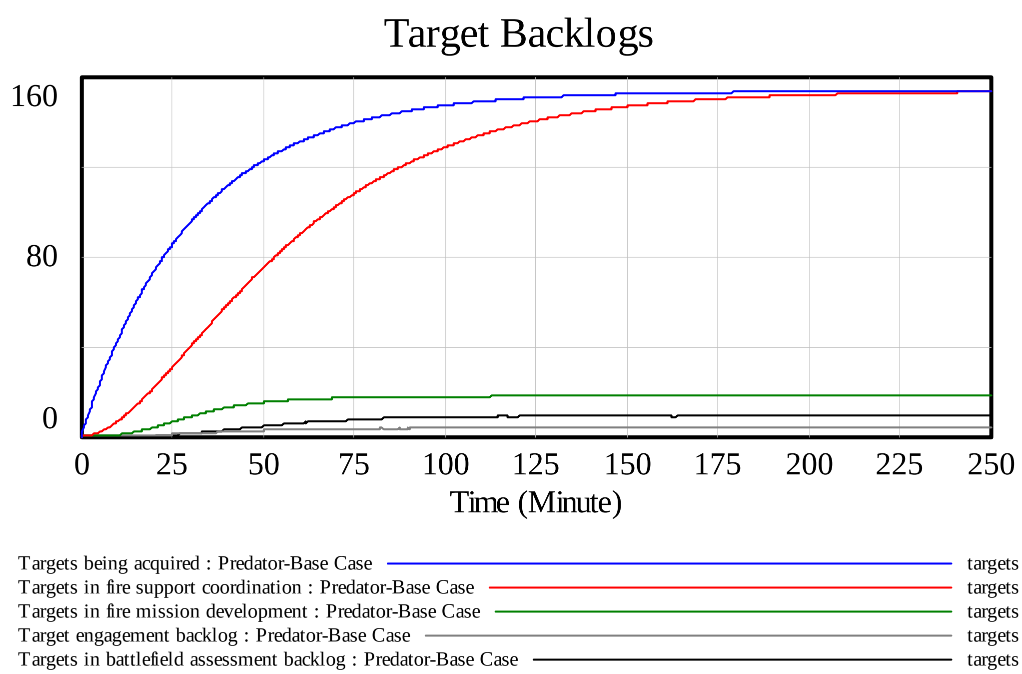
Model Calibration and Testing

The KVA+SD model was calibrated to the operations of four actual weaponized UAVs. The operations included the following subprocesses:

1. acquire target,
2. fire support coordination,
3. fire mission development,
4. move weapons,
5. engage targets, and
6. perform battlefield assessments.

Three of the four UAVs are operational: Predator, Sky Warrior, and Reaper. The fourth UAV is the X-47B. The modelers collected basic characteristics relating to UAV performance for the four UAVs from publicly available sources (such as Global Security, 2010). That information included vehicle range, total mission time, time on station, dash speed, and payload. The DoD has developed multiple versions of some of the vehicle with different characteristics. In these cases, a single version was selected and used. Other information was estimated for each vehicle's operations, including learning and processing times for each subprocess. Reasonable assumptions were used in making these estimates; for example, we made the assumption that the time required to engage a target after arriving on station was inversely proportional to the vehicle's dash speed (i.e., faster dash speeds reduced the time required to engage). These estimates were rough but adequate for this proof-of-concept study, which sought to determine if the model was capable of reflecting differences in characteristics in KVA parameters, not whether it was capable of predicting actual outcomes.

The model was tested using standard tests for system dynamics models (Forrester & Senge, 1980; Sterman, 2000), including for structural similarity to the actual system, reasonable behavior over a wide range of input values, and behavior similarity to actual systems. Basing the model structure on previously validated models and the literature improves the model's structural similarity to actual acquisition projects. Model behavior (e.g., simulated sizes of backlogs for subprocesses and rates of performing operations) was compared to typical behavior and found to be similar. For example, before operations started at the beginning of the operational scenario (described in what follows), the backlogs were empty and no operations were being performed. The appearance of targets increased subprocess backlogs and rates of operation as weapons left base and subsequently arrived on station, acquired targets, coordinated fire, developed missions, engaged targets, and assessed the battlefield. Figure 5 shows an example of these simulated backlogs for the Predator UAV.



NOTE: Target Backlog is measured in the number of targets

Figure 5. Backlogs in the Target Evolution Sector—Predator UAV Base Case

In the evolution of targets, these backlogs and subprocesses increase sequentially through the series of operations. The growth of operations and backlogs slows as capacities adjust to demand (backlog sizes) until the operations are in dynamic equilibrium conditions, with sizes of backlogs and operations rates remaining within a relatively narrow range. This represents "steady state" operations that could be continued for a significant period of time, e.g., until damage to weapons or maintenance (not included in the current model) changes weapon availability. Model behavior was also tested with extreme input values such as perfect operations (e.g., probability of hit=100%) and a very large versus very small number of weapons and targets as well as with more typical conditions. Model behavior remained defensible across wide ranges of input values, including extreme values. These tests increased modeler confidence that the model generates realistic operational behavior patterns due to the same causal relations found in the type of operations investigated (i.e., generates "the right behavior for the right reasons").

The operational scenario was described with the quantity and characteristics of the targets.[6] A stream of targets entered the target acquisition backlog at a steady rate of five targets per minute. The target distance from the base was assumed to vary uniformly from 400–1,100 nm. This distance described targets including those that were closer to the weapon's base than the shortest weapon's range to targets that were farther from the base than the longest weapon's range. The speed of the targets was assumed to vary uniformly from 50 to 250 nm. This described targets from those that were almost immobile to targets that were faster than the fastest weapon modeled. The payload required to destroy the target if hit (i.e., lethal payload) was assumed to vary uniformly from 400 to 1,000 lbs. This described targets from those that were very soft to targets that were very hardened.

KVA productivities for the six subprocesses and the cumulative productivity of those processes for the four weaponized UAVs are shown in Table 2. Each KVA

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[6] Although a single operational environment was simulated for this research, multiple and different environments can be simulated. Examples of characteristics of the operational scenario that can be elaborated include dynamic variation in the entering target rate, distributions of target characteristics, and more target characteristics.

productivity ratio is described as the integer resulting from dividing the benefits (in Learning Time) by the cost (in Touch time). For example,, for the Fire Mission Development subprocess for the four UAVs those ratios are 943 (Predator), 3,122 (Reaper), 1,222 (Sky Warrior), and 3,962 (X-47B). They represent the benefits (output) per unit of cost (input) and, therefore, can also be interpreted as a measure, in percentages, of the return on the investment. These values remained constant in the model after steady state operations had been established. As an example of the components of the ratios, the Fire Mission Development subprocess ratio for the Predator (943) is the quotient of the accumulated benefits (e.g., after five hours of operations) of 79,684 learning-time hours and 84.5 processing-time hours. In the simulated steady state operations, these accumulated learning-time hours increased at a rate of 301 learning-time hours per minute (the product of the estimated 500 learning-time hours per fire development operation and an average fire development rate of 0.6 targets developed per minute), and the processing-time hours increased at a rate of 0.3 hours per minute (the product of the estimated 30-minute processing time to develop a fire mission and the same average fire development rate of 0.6 targets developed per minute). Transitional periods (e.g., the start or end of operations) or other nonsteady state operations can generate ratios that vary over time.

Table 2. KVA Productivity Ratios

		Weaponized UAV			
		Predator	Reaper	Sky Warrior	X-47B
Subprocess Productivity	Acquire targets	377	377	377	377
	Fire support coordination	189	189	189	189
	Fire mission development	943	3122	1222	3962
	Move weapons	50	23	44	607
	Engage targets	5094	70761	15212	254736
	Battlefield assessment	377	377	377	377
	Weapon	705	907	954	1067

Note that, as described in The KVA Sector section, these productivities are ratios of accumulated learning time divided by accumulated processing time. Therefore, they are relative values. As expected, the three productivities for the subprocesses that were not impacted by the characteristics of the vehicle (acquire targets, fire support coordination, and battlefield assessment) did not change. These subprocesses were not impacted by different vehicles because the subprocess was the same for all of these vehicles. The application of system dynamics and KVA to the Analysis of Alternatives of other system alternatives—such as improved logistics or vehicle technology used for recognizing and indentifying targets—would generate changes in these KVA productivities. However, three important subprocesses that impacted total product productivity (see the row titled *Weapon* in Table 2) did vary (fire mission development, move weapons, and engage targets).

Some of the ratios in Table 2 are relatively large when compared to returns on investment experienced in many industries, especially for the Engage targets subprocess. A primary reason is that the numerator of these ratios includes the benefits of the technologies incorporated into the UAV for target engagement purposes. These technologies are extremely complex, are reflected in very large learning-time hours that are accumulated each time a target is engaged, and, therefore, generate high productivity ratios. Similarly, the denominator of these ratios reflects the time required to perform the subprocess, e.g., engage a target after it has been acquired, coordinate fire support, develop fire missions, and move UAVs to stations. Actual engagement times are relatively short for these UAVs, further increasing the KVA productivity ratios for the engage target subprocess. Differences in learning times across the UAVs reflect their relative performance (e.g., the automation of subprocesses previously performed by humans). Technologies are the primary causes of differences in the ratios across the UAVs in Table 2. Therefore, it is reasonable that the very large benefits of the X-47B, with its extremely advanced technology, generate the largest ratios. Improved estimates of learning times and processing times can increase the accuracy of these ratios. However, a comparison of the KVA productivity ratios for the engage targets subprocess with the ratios for the move weapons subprocess, which is simpler (lower numerator) and takes longer (larger denominator), indicates that the rank order of the ratios reflects the relative returns of the different subprocesses.

Based on these and additional tests, the model is considered useful for the investigation of the integration of system dynamics and KVA. Table 2 indicates that the X-47B is the most efficient (generates more benefits for given costs). The next section uses the model to generate a deeper understanding of how subprocesses contribute to overall weapon productivity. .

Using System Dynamics and KVA to Improve Analysis of Alternatives

Consider the following hypothetical example of the use of an integrated system dynamics/KVA model to improve the productivity estimates supporting an Analysis of Alternatives. Assume that a new version of the Predator UAV is being developed to enable it to engage opposing UAVs. Due to the much higher speeds and agility of UAVs compared to most land-based targets, the fraction of targets missed is expected to be higher than that currently experienced with the Predator. The acquisition program management team has access to some, albeit limited, resources (e.g., money, expert developer time until required delivery, technology development capabilities, approvals) to improve performance. Different stakeholders value payload, dash speed, and range differently and want the program management to recommend different improvements. Therefore, program management expects a rigorous review of its Analysis of Alternatives process and the results that will recommend one (and only one) of the improvements. As part of the justification of the AoA decision, stakeholders of the two solutions not recommended are certain to require explanations of how and how much the recommended improvement will impact operational performance compared to the improvements that were not recommended. Cost would, most likely, be their primary economic consideration, as evidenced by the earlier case-study examples. However, our analysis will focus on value compared to cost in terms of the capabilities of the systems.

Many alternatives have been proposed and are being considered. A few examples are[7]:

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[7] There are interdependencies and trade-offs in these alternatives, such as needing to increase the size of the power plant to maintain a given dash speed if the size of the fuel tank is increased. These are ignored here for simplicity. However, in an application to an actual program, developers would describe specific sets of features (e.g., possible versions of a vehicle) for analysis.

- Increase the size of the power plant, which can be used to increase the vehicle's payload, dash speed, or a combination of both. This requires an increase in fuel capacity in order to not reduce range.
- Redesign the transmission, which will increase the vehicle's dash speed.
- Increase the fuel tank size, which will increase the vehicle's range but decrease its dash speed unless the power plant is also increased.
- Reduce the time required at base between trips to station, which will increase the time that the vehicle is on station and available for missions.

Performing detailed analyses of all the possible alternatives, such as by building and testing prototypes or very detailed simulations, can exceed the resources of acquisition programs. Therefore, program managers may be faced with the challenge of reducing a long list of potential alternatives to those that should definitely be included in the program, those that should be investigated further for potential inclusion, and those that should be rejected. The integration of system dynamics and KVA provides a timely and inexpensive means of evaluating all potential alternatives and reducing the long list of potential alternatives to a short list to be pursued or investigated further based on an objective and justifiable process. To do this, the operation of the system with each potential alternative must first be simulated. This simulation can provide insight into system operations based on different investment decisions. For example, Figure 6 shows the simulated evolution of the backlog of targets waiting for engagement based on three investment choices: an increased power plant that doubles the allowable payload (100% power plant payload), a Predator without improvement (Predator base case), and a redesigned transmission that doubles the vehicle's dash speed (100% faster dash speed). These can be used to improve CONOPS (e.g., the number of different types of assets allocated).

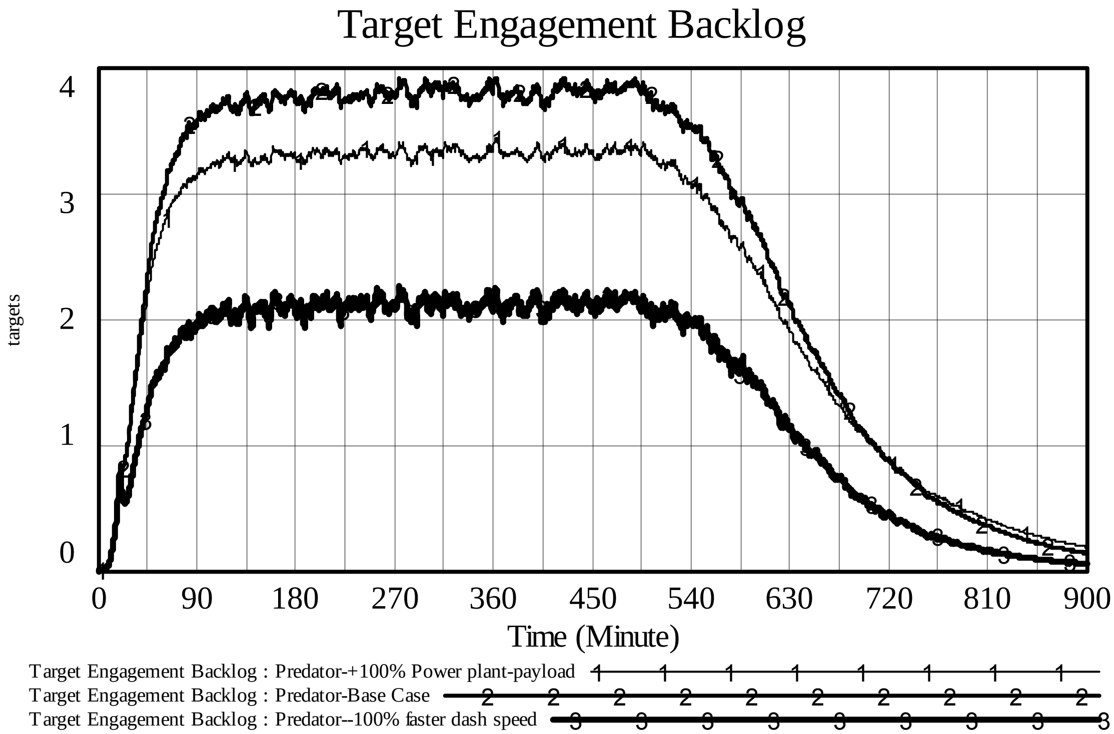

Figure 6. Engagement Backlog Evolution for Five Predator Investment Choices

The simulations can also be used to calculate the KVA productivity ratios for the subprocesses and for the system as a whole. Table 3 provides an example of a portion of such an analysis for the hypothetical upgrading of the Predator UAV using the model described in the A Generic Model of Mobile Weapons Use section. .

Table 3. Predator UAV Upgrade Program

		Subprocess			System	
		Fire mission development	Move weapons	Engage targets	Weapon	Change vs. base case
	Predator base Case	943	50	5,094	705	0%
Improvement Alternative	Increase fuel capacity 100%	**1,886**	50	5,094	**951**	**35%**
	Increase fuel capacity 50%	1,415	50	5,094	831	18%
	Increase power plant 50% for payload	943	51	7,641	796	13%
	Increase power plant 100% for dash speed	943	**100**	**10,188**	741	5%
	Redesign transmission for 100% faster dash speed	943	78	**10,188**	731	4%
	Increase power plant 50% for dash speed	943	75	7,641	727	3%
	Increase power plant 100% for payload	943	50	**10,188**	722	2%
	Redesign transmission for 50% faster dash speed	943	78	7,641	717	2%
	Reduce time at base 50%	943	50	5,094	699	-1%
	Reduce time at base 100%	943	52	5,094	693	-2%

KVA Productivity Ratios for Analysis of Alternatives

The KVA productivity ratios are repetitive for some subprocesses across alternatives. This is partially because some alternatives do not change the impact on some subprocesses and partially because of the limited number of system interactions incorporated into this proof-of-concept model. However, the results from using an integrated system dynamics/KVA model are adequate to show how more accurate results might be used in an AoA of potential capabilities upgrades. Based on the results above, a program manager can assess the relative value added by the eleven alternatives (including no change, as reflected by the Base Case) analyzed. A comparison to the base case (e.g., the existing vehicle in the case of the Predator upgrade) provides an estimate of relative performance improvement. By sorting the improvements provided by potential alternatives in decreasing order (Table 3), we created a list of alternatives from most attractive (increase fuel capacity 100%) to least attractive (reduce time at base 50%). The AoA suggests that if adequate resources are available, then the alternative that improves the system the most is to increase the fuel capacity 100% because it improves the development of the fire missions. If inadequate resources are available to implement this alternative, then the program should attempt to increase the fuel capacity by 50% for similar reasons. The program manager can also remove from consideration reducing the time at the base and a 50% increase in power plant capacity that would be used to increase dash speed because they do not improve performance. Certainly other factors must be incorporated into a complete AoA (most notably development costs), but the results of the KVA analysis using the system dynamics model provide valuable information for making final recommendations.

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Discussion and Conclusions

Summary

The Knowledge Value Added (KVA) approach to including benefits in an Analysis of Alternatives (AoA) was integrated with a system dynamics model of weapon systems operations to investigate the potential of their integration to improve the accuracy of KVA productivity ratios and, thereby, AoA. An integrated model was developed for a generic mobile weapons system and calibrated to four existing weaponized Unmanned Aerial Vehicles (UAV). Six basic subprocesses of operations using the weapons were included in the simulation. KVA productivity ratios for each subprocess for each UAV were calculated, compared, and used to explain how the simulation and KVA approach work together to generate quantitative assessments of the relative value added of each subprocess and whole weapon system. A hypothetical upgrade program to one of the UAVs was also simulated to demonstrate how the integrated model can be used to evaluate alternative upgrades and justify AoA decisions.

Evaluation of Results

An Analysis of Alternatives based on an integrated system dynamics/KVA model provides program management teams with several kinds of valuable information:

- **Quantified Measures of Improvement that include Benefits:** Measures of subprocesses and the weapon system as a whole are quantified using a common set of assumptions and values (those incorporated into the simulation model). Therefore, differences in ratios and the implied relative value of different alternatives are due to the differences in the alternatives themselves.
- **Overall System Improvement Estimates:** The weapon (versus the subprocess) -productivity ratios reflect changes in total product operations. If adequate resources are available to adopt at least one alternative, then a list of alternatives ranked by overall system improvement (e.g., Table 3) can be used to "triage" alternatives into

those that should definitely be pursued, those that require more investigation before deciding, and those that should be abandoned. For example, the right-hand column in Table 3 suggests that increasing the fuel capacity should be pursued before redesigning the transmission and that reducing the time at the base should not be considered further.

- **Guidance for Alternative Selection:** The analysis specifically identifies which alternatives improve which subprocesses and the whole weapon system and by how much. For example, Table 3 suggests that increasing fuel capacity increases the Fire mission development subprocess most, and three alternatives significantly improve the engage target subprocess most.

- **Justification of Analysis of Alternatives Decisions:** When used with the simulation model, the KVA productivity ratios can help explain and justify Analysis of Alternatives decisions by providing a means of describing how each alternative impacts operations, subprocesses, and performance. For example, in the UAV case above, increasing power plant size increases the payload, which increases the payload/lethal payload ratio, which increases the probability of destruction if hit (p(kill)), which decreases the return flow "Incomplete kill rate" from the Battlefield Assessment Backlog to the Target engagement backlog (Figure 3). This reduces the average number of times that a target must be engaged in order to be destroyed, thereby improving the productivity of the engage target subprocess.

- **Guidance for Further Investigation:** In addition to suggesting better and worse alternatives to pursue, an integrated system dynamics/KVA model can provide guidance for further investigation of alternatives by indicating which subprocesses each alternative improves. For example, Table 3 indicates that the reason that increasing fuel capacity improves performance is that it improves the Fire mission development subprocess. The model (Figure 3) indicates that this occurs by increasing the vehicle range, which reduces the likelihood of losing a target if it is missed with ordinance. Acquisition program managers can use this information to focus further investigation and development of this alternative on fire mission development to assure that these improvements in the specific operations identified with the model are realized during the alternative's development.

It is important to note that neither a system dynamics model nor a KVA analysis of this system alone can reasonably produce these results. Only by integrating system dynamics and the KVA approach are the benefits above available. Based on the modeling and assessment above, we conclude that integrated system dynamics/KVA models can significantly improve the Analysis of Alternatives and, thereby, acquisition.

Implications for Practice

The current work indicates that acquisition can be improved by using integrated system dynamics/KVA models in the Analysis of Alternatives. The rigorous development and use of integrated system dynamics/KVA models can have important implications for acquisition practice, including the following:

- The number of alternatives that can be analyzed with KVA can be increased due to the relative ease of reflecting alternatives in the operations simulation model compared to manually developing forecasts for use in KVA analysis. This increases the likelihood of identifying and selecting the optimal alternative.
- Justifications of AoA decisions can become stronger due to program managers having the ability to causally trace from specific alternatives through their impacts on specific subprocesses and operations to performance.
- Justifications of an AoA decisions can become more robust because they can reflect an analysis of a wider range of alternatives and more alternatives.
- Results of AoA can become more consistent through the use of a single, integrated model of system operations and KVA metrics instead of separate operations and value-added models.
- System dynamics/KVA models may be used to baseline product performance during the acquisition process. Performance of the product can be tracked over time and used to improve the model and, thereby, performance forecasts and AoA later in acquisition.
- ***Program management will select better alternatives*** due to the implications for practice listed in the bullets immediately above. This will generate more effective and potentially cheaper materiel solutions.

In addition, improving the AoA and acquisition through integrated system dynamics/KVA models can improve CONOPS. The Javelin case study provides a vivid example of the ability of acquisition in general and improved AoA to impact tactics and strategy. Upon receipt and use of Javelin, operators expressed surprise that its range was twice that of the weapon it replaced. That increased range initiated improvements to tactics, techniques, and procedures (ttp) such as the use of Javelin to detonate improvised explosive devices. This, in turn, could generate changes to strategies. Accurate forecasts of product subprocess performance (e.g., accuracy at longer range) could be used to plan CONOPS improvements before product delivery.

It is important to note that the purpose of the simulations of operations developed and illustrated in the current work was to capture the relative benefits and costs of different materiel alternatives, not to simulate the impacts of operations on opposing forces. The usefulness of models can only be judged in relation to the specific purpose for which they are built (Sterman, 2000). Therefore, because the purpose of integrated system dynamics/KVA models is to improve AoA, those models should be developed, assessed, and used separately from force-on-force and other simulations of operations developed for other purposes.

Future Work

The current proof-of-concept work has demonstrated the potential of integrated system dynamics/KVA models to improve an Analysis of Alternatives and acquisition. Additional research can extend this work toward implementation and expanded application. Opportunities include the following:

- Modeling a specific acquisition program in support of its Analysis of Alternatives process can develop and demonstrate the capability of operationalizing the approach tested here.
- If important uncertainties in system operations are incorporated into the system dynamics model, then it can be used to generate distributions of KVA productivities. These can be used to estimate the volatilities used in real options analysis, which has been demonstrated to be useful in DoD acquisition.
- The application of integrated system dynamics/KVA modeling to DoD product lifecycle management can be investigated by using the model

to generate forecasts of performance and KVA ratios during acquisition, comparing those forecasts with actual operations, and using the results to improve the model fidelity with the system. The improved model can then be used to analyze proposed changes or replacement of the system throughout its lifecycle.

The Analysis of Alternatives is a particularly challenging part of DoD acquisition. Integrating system dynamics modeling and the Knowldege Value Added approach has been shown to be capable of improving that analysis and, thereby, alternative selection. Adapting this approach can significantly change and improve DoD acquisition practice.

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List of References

Abdel-Hamid, T. (1988). Understanding the “90% syndrome” in software project management: A simulation-based case study. *Journal of Systems and Software*, *8*, 319–330.

Bakken, B. E. (2004). The Atlantic defense technology gap: Will it be closed? In *Proceedings of the 22nd International Conference of the System Dynamics Society*. Oxford, England: International System Dynamics Society.

Bakken, B. E. & Gilljam, M. (2003). Dynamic intuition in military command and control : Why it is important, and how it should be developed. *Cognition, Technology and Work*, *5*, 197–205.

Bakken, B. E., Gilljam, M., et al. (2004). Perception and handling of complex problems in dynamic settings: Three cases of relevance to military command and crisis management. In *Proceedings of the 22nd International Conference of the System Dynamics Society*. Oxford, England: International System Dynamics Society.

Bakken, B. T., Ruud, M., et al. (2004). The system dynamics approach to network centric warfare and effects based operations: Designing a "learning lab" for tomorrow. In *Proceedings of the 22nd International Conference of the System Dynamics Society*. Oxford, England: International System Dynamics Society.

Bakken, B. T., & Vamraak, T. (2003). Misperception of dynamics in military planning: Exploring the counter-intuitive behaviour of the logistics chain. In *Proceedings of the 21st International Conference of the System Dynamics Society*. New York: International System Dynamics Society.

Bartolomei, J. (2001). A system dynamics model of government engineering support during the development phase of a military acquisition program. In *Proceedings of the 19th International Conference of the System Dynamics Society*. Atlanta, GA: International System Dynamics Society.

Bell, J. W., Jr., & Liphard, R. E. (1978). A system dynamics model of the Department of Defense enlisted force for investigation of alternative retirement proposals (GPO Report Number: ADA065970). Wright-Patterson AFB, OH: Air Force Institute of Technology.

Cayas, C. P. (2007). Northrop wins Navy UCAS bid over Boeing. Retrieved from http://www.navytimes.com/news/2007/08/defense_ucas_northrop_070801/

Chairman of the Joint Chiefs of Staff (CJCS). (2009, March). Joint Capabilities Integration And Development System (CJCS Instruction 3170.01g). Washington, DC: CJCS.

Cooper, K. G. (1980). Naval ship production: A claim settled and a framework built. *Interfaces*, *10*(6), 20–36.

Cooper, K. G. (1993a). The rework cycle: Benchmarks for the project managers. *Project Management Journal*, *14*(1), 17–21.

Cooper, K. G. (1993b). The rework cycle: How it really works…and reworks. *PM Network*, 25–28.

Cooper, K. G. (1993c). The rework cycle: Why projects are mismanaged. *PM Network*, 5–7.

Copper, K. G. (1994). The $2,000 hour: How managers influence project performance through the rework cycle. *Project Management Journal*, *15*(1), 11–24.

Cooper & Mullen. (1993). "Swords and Plowshares: The Rework Cycles of Defense and Commercial Software Development Projects." American Programmer 6(5): 41 - 51.

Coyle, R. G. (1996, August). System dynamics applied to defense analysis: A literature survey. *Defense & Security Analysis*, *212*(2), 141–160.

Coyle, R. G., & Gardiner, P. A. (1991). A system dynamics model of submarine operations and maintenance schedules. *Journal of the Operational Research Society*, *42*(6), 453–462.

Department of Defense (DoD). (2006). *Defense acquisition guidebook* (Ver. 1.6). Retrieved from http://akss.dau.mil/dag

Duczynski, G. (2000). Profiler: An "Effects-based" military capability manager. In *Proceedings of the 18th International Conference of the System Dynamics Society* (p. 59). Bergen, Norway: International System Dynamics Society.

Flood, R. L., & Jackson, M. C. (1991). *Creative problem solving: Total systems intervention*. Chichester, UK: Wiley.

Ford, D. (2002). Achieving multiple project objectives through contingency management. *ASCE Journal of Construction Engineering and Management*, 128(1), 30–39.

Ford, D. N., & Dillard, J. T. (2008). Modeling the integration of open systems and evolutionary acquisition in DoD programs. In *Proceedings of the Fifth Annual*

Acquisition Research Symposium. Monterey, CA: Naval Postgraduate School.

Ford, D. N., & Dillard, J. T. (2009a). Modeling open architecture and evolutionary acquisition in ARCI with applications to RCIP. In *Proceedings of the Sixth Annual Acquisition Research Symposium*. Monterey, CA: Naval Postgraduate School.

Ford, D. N., & Dillard, J. T. (2009b). Modeling the performance and risks of evolutionary acquisition. *Defense Acquisition Review Journal*, *16*(2), 143–158.

Ford, D., & Sterman, J. (1998). Modeling dynamic development processes. *System Dynamics Review*, *14*(1), 31–68.

Ford, D., & Sterman, J. (2003a). The liar's club: Impacts of concealment in concurrent development projects. *Concurrent Engineering Research and Applications*, *111*(3), 211–219.

Ford, D., & Sterman, J. (2003b). Overcoming the 90% syndrome: Iteration management in concurrent development projects. *Concurrent Engineering Research and Applications*, *111*(3), 177–186.

Forrester, J. W. (1961). *Industrial dynamics*. Portland, OR: Productivity Press.

Forrester, J. W. and P. M. Senge (1980). Tests for Building Confidence in System Dynamics Models. System Dynamics. A. A. Legasto, Jr. and e. al. New York, North-Holland. 14: 209-228.

Global Security. (2010, March 22). Unmanned Aerial Vehicles (UAVs). Retrieved from http://www.globalsecurity.org/intell/systems/uav-intro.htm

Government Accountability Office (GAO). (2007, February). Assessing risks and returns: A guide for evaluating federal agencies' IT investment decision-making (Version 1). Washington, DC. GAO.

Government Accountability Office (GAO). (2009). *Cost estimation guide*. Washington, DC. GAO.

Homer, J. B., & Somers, I. (1988). Defense program lifecycle management: A dynamic model for policy analysis. In *Proceedings of the 1988 International System Dynamics* Conference. International System Dynamics Society:.

Housel, T. J., & Kanevsky, V. (1995). Reengineering business processes: A complexity theory approach to value added. *INFOR*, *33*, 248–262.

Jackson, M. C. (2003). *Systems thinking: Creative holism for managers*. Chichester, UK: Wiley.

Joglekar, N., & Ford, D. (2005). Product development resource allocation with foresight. *European Journal of Operational Research*, *160*(1), 72–87.

Jones, C. A. (1997). Unmanned Aerial Vehicles (UAVs): An assessment of historical operations and future possibilities. Report AU/ACSC/0230D/97-03. Research Department, Air Command and Staff College. http://www.fas.org/irp/program/collect/docs/97-0230D.pdf.

Lane, D. C., & Jackson, M. C. (1995). Only connect! An annotated bibliography reflecting the breadth and diversity of systems thinking. *Systems Research*, *12*, 217–228.

Lee, Z., Ford, D., & Joglekar, N. (2007). Effects of resource allocation policies for reducing project durations: A systems modeling approach. *Systems Research and Behavioral Science*, *24*(6), 551–566.

Lyneis, F., Cooper, K., & Els, S. (2001). Strategic management of complex projects: A case study using system dynamics. *Systems Dynamics Review*, *17*(3), 237–260.

Lyneis, J. M., & Ford, D. N. (2007). System dynamics applied to project management: A survey, assessment, and directions for future research. *System Dynamics Review*, *23*(4), 157–189.

Marks, W. (2010, February, 2). X-47B unmanned combat air system taking shape on board Lincoln. Retrieved from http://www.navy.mil/search/display.asp?story_id=51239

McLucas, A. C., Lyell, D., et al. (2006). Defence capability management: Introduction into service of multi-role helicopters. In *Proceedings of the 24th International Conference of the Systems Dynamics Society* (p. 92). Nijmegen, The Netherlands: International Systems Dynamics Society.

Melhuish, J., Pioch, N., et al. (2009). Improving military strategy using predictive agents with embedded mental simulation models. In *Proceedings of the 27th International Conference of the System Dynamics Society*. Albuquerque, NM: International System Dynamics Society.

Northrup Grumman. (2010). X-47B Pegasus UCAV-N. Retrieved from http://www.globalsecurity.org/military/systems/aircraft/x-47b.htm

Northrup Grumman. (2010). X-47B UCAS. Retrieved from http://www.as.northropgrumman.com/products/nucasx47b/index.html

Pavlou, P., Housel, T. J., Rodgers, W., & Jansen, E. (2005). Measuring the return on information technology: A knowledge-based approach for revenue allocation at the process and firm level. *Journal of Association of Information Systems*, *6*(7), 199–226.

Rodgers, W., & Housel, T. J. (2006). Improvement of global performance measures related to intangible assets. In *Collected Papers of the 32nd European International Business Academy (EIBA) Conference*. Fribourg, Switzerland: EIBA.

Sterman, J. S. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. New York: Irwin McGraw-Hill.

Taylor, T. R., & Ford, D. N. (2006). Tipping point dynamics in development projects. *System Dynamics Review*, *22*(1), 51–71.

Taylor, T. R., & Ford, D. N. (2008, June). Managing tipping point dynamics in development projects. *ASCE Journal of Construction Engineering and Management*, *134*(6), 421–431.

Under Secretary of Defense (Acquisition, Technology, & Logistics (USD[AT&L]). (2007, September 19). *Prototyping and competition* [Memorandum]. Location: Washington, DC.

Watts, K. M., & Wolstenholme, E. F. (1990). The application of a dynamic methodology to assess the benefit of a logistics information system in defense. In *Proceedings of the 1990 International System Dynamics Conference: System Dynamics '90* (p. 1286). Chestnut Hill, MA: International System Dynamics Society.

Williams, A. J. (2001, May). Air support functionality in AFATDS—Advance field artillery tactical data system. *FA Journal*. Retrieved from http://findarticles.com/p/articles/mi_m0IAU/is_3_6/ai_76610396/

Department of Defense (2005). Information Technology Portfolio Management (DoD Directive 8115.01). Washington, DC: DoD.

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Appendix A. The System Dynamics Model

Max asset range available=RANDOM UNIFORM(0, 1, 9876) ~ Dmnl
Asset available range="Asset max. range"*Max asset range available
~ NauticalMiles
~ |

"Avail Range: Traget distance from base ratio"=(Asset available range/Target distance fr base)+0.01 ~ Dmnl
~ |

Confirm kill rate=Battlefield assessment rate*Fraction not confirmed kill
~ target/Minute
~ |

Change Battlefliedl assessment capacity applied=Max(-0.5*Battlefield assessment capacity applied,Avg Battlefield assessment delay*Sesnativity of Battlefield assessment capability to Avg Battlefield assessment delay)
~ (targets/Minute)/Minute
~ |

Fraction not confirmed kill=Min(1,"p(incomplete kill)"+"p(lose target after miss)"+"p(missed but not lost)") ~
~ |

"Dash speed: Target speed ratio"=(Asset dash speed/Target speed)+1 ~ Dmnl
~

"p(not lose target)"= "Range-p(not lose) function"("Avail Range: Traget distance from base ratio") ~ Dmnl
~ |

"Range-p(not lose) function"([(0,0)-(2,1)],(0,0),(0.740061,0.0482456),(0.911315,0.127193),(1.34557,0.912281),(1.55963,0.951754),(1.85933,0.951754)) ~ |

"Payload: Lethal payload ratio"=(Asset payload/Lethal payload)+0.01 ~ Dmnl
~ |

"Payload - p(kill) function"([(0,0)-(10,1)],(0,0),(1,1),(10,1)) ~ |

"Speed-p(hit) function"([(0,0)-(4,1)],(0,0),(0.40367,0.0219298),(0.648318,0.0482456),(0.892966,0.0877193),(1.24771,0.447368),(1.57798,0.745614),(1.89602,0.868421),(2.28746,0.903509),(2.59327,0.903509),(2.99694,0.903509))

~
Lethal payload=RANDOM UNIFORM(400, 1000, 1234) ~ lbs
~ |
"p(hit target)"="Speed-p(hit) function"("Dash speed: Target speed ratio") ~ Dmnl
~ |
"p(kill target if hit)"= "Paylod - p(kill) function"("Payload: Lethal payload ratio")
~ Dmnl
~ |
Target speed= RANDOM UNIFORM(50, 250, 1234) ~ knots
~
Target distance fr base=RANDOM UNIFORM(400, 1100, 1234)
~ NauticalMiles

~ |
Mission fraction sent to asset=Min(1,Max(0,Reference Mission fraction sent to asset+(Targets in fire mission development*Sensativity of Mission Fraction Sent to Asset to Backlog))) ~ Dmnl

~ |
"Fire support - missions not assigned to asset"=Fire support coordination completion rate-Fire support coordination to asset rate ~ target/Minute

~ |
Targets in battlefield assessment backlog= INTEG (Engage target rate-Confirm kill rate-Incomplete kill rate-Miss target but have not lost target rate-Lose target after miss rate,0) ~ targets

~ |
Total confirmed target kills= INTEG (Confirm kill rate,0) ~ targets
~ |
Avg Battlefield assessment delay=ZIDZ(Targets in battlefield assessment backlog,Confirm kill rate)~ Minute

~ |
Targets in fire support coordination= INTEG (Acquire target completion rate-Fire support coordination to asset rate-"Fire support - missions not assigned to asset",0)

~ targets

~ |
Total targets not assigned to asset= INTEG ("Fire support - missions not assigned to asset",0) ~ targets
~ |
Asset payload=GET XLS CONSTANTS('Input.xls','Input','c22') ~ lbs

~ |

Target ID rate=IF THEN ELSE(Time<480, 5, 0) ~ targets/Minute

~ |

"Asset max. range"=GET XLS CONSTANTS('Input.xls','Input','c24')

~ NauticalMiles

~ |

Asset dash speed=GET XLS CONSTANTS('Input.xls','Input','c23') ~ knots

~ |

Cumm Project Learning Time earned= INTEG (Earn Project Learning Time,0)

~ LThours

~ |

Cumm Project Touch time spent= INTEG (Spend Project Touch Time,0)

~ TThours

~ |

Fire support coordination completion rate= Min(Fire support coordination capacity applied,Targets in fire support coordination/Avg Fire support coordination duration) ~ targets/Minute

~ |

Fire support coordination to asset rate=Fire support coordination completion rate*Mission fraction sent to asset ~ targets/Minute

~ |

Reference Mission fraction sent to asset=GET XLS CONSTANTS('Input.xls','Input','c16') ~ Dmnl

~ |

Spend engagement touch time=Engage target rate*Avg Engagement duration*"unit Touch Time hours spent per duration minute (targets)" ~ TThours/minutes

~ |

Spend fire mission development touch time= Fire mission completion rate*Avg Fire mission development duration*"unit Touch Time hours spent per duration minute (targets)" ~ TThours/minutes

~ |

Earn Project Learning Time="Earn LT - acquire targets"+"Earn LT - Battlefield assessment"+"Earn LT - Engage targets"+"Earn LT - Fire mission development"+"Earn LT - Fire support coordination"+"Earn LT - Move assets"

~ LThours/Minute

~ |

Targets in fire mission development= INTEG (+Fire support coordination to asset rate+Miss target but have not lost target rate-Fire mission completion rate,0)

~ targets

~ |

Sensativity of Mission Fraction Sent to Asset to Backlog=-0.05 ~ 1/targets

~

Spend Project Touch Time=Spend battle assessment touch time+Spend engagement touch time+Spend fire mission development touch time+Spend fire support coordination touch time+Spend target acquisition touch time+Total spend move asset touch time ~ TThours/minutes

~ |

"Earn revenue - Fire mission development"= Fire mission completion rate*"Unit revenue - Fire mission development" ~ kdollars/Minute

~ |

"Earn LT - Move assets"=Total move asset rate*Move asset unit learning time*"Avg no. of targets that each asset can engage at once" ~ LThours/Minute

~ |

Fire mission completion rate=Min(Fire mission development capacity applied,Targets in fire mission development/Avg Fire mission development duration)

~ targets/Minute

~ |

Project productivity=XIDZ(Cumm Project Learning Time earned,(Cumm Project Touch time spent*Relative value of LT compared to TT),1) ~ Dmnl

~ |

Engage target rate=Min(Target engagement backlog,Targets assets on station can engage)/Avg Engagement duration~ targets/Minute

~

Assets in route to Base= INTEG (Assets leave station for base rate-Assets arriving at base rate,0) ~ Assets

~ |

Assets arrive at station rate=Assets in route to Station/Avg travel time to or from station ~ Assets/Minute

~ |

Assets arriving at base rate=Assets in route to Base/Avg travel time to or from station ~ Assets/Minute

~ |

Assets at Base= INTEG (Assets arriving at base rate-Assets leaving base for station rate,Number of assets applied) ~ Assets

~ |

Avg travel time to or from station=GET XLS CONSTANTS('Input.xls','Input','m7')

~ Minute

~ |

Assets leave station for base rate=Assets on Station/Avg time on station

~ Assets/Minute

~ |

Assets leaving base for station rate=Assets at Base/Avg time at base

~ Assets/Minute

~ |

Avg time at base=GET XLS CONSTANTS('Input.xls','Input','m11') ~ Minute

~ Assumed to be the average time from arrival of the asset at the base that \is required to refuel and reload asset and have it depart from base.

|

Incomplete kill rate=Battlefield assessment rate*"p(incomplete kill)"

~ targets/Minute

~ |

"Spend move asset touch time-base to station"=Assets leaving base for station rate*Avg travel time to or from station*"unit Touch Time hours spent per duration minute (assets)" ~ TThours/minutes

~ |

"Spend move asset touch time-station to base"=Assets leave station for base rate*Avg travel time to or from station*"unit Touch Time hours spent per duration minute (assets)" TThours/minutes

~ |

Miss target but have not lost target rate=Battlefield assessment rate*"p(missed but not lost)"

~ targets/Minute

~ |

Total move asset rate=Assets leave station for base rate+Assets arriving at base rate ~ Assets/Minute

~ |

Lose target after miss rate=Battlefield assessment rate*"p(lose target after miss)"~targets/Minute

~ |

Targets being acquired= INTEG (+Target ID rate+Lose target after miss rate-Acquire target completion rate,0) ~ targets

~ |

Targets assets on station can engage=INTEGER(Assets on Station*"Avg no. of targets that each asset can engage at once") ~ targets

~ |

"p(missed but not lost)"=(1-"p(hit target)")*(1-"p(not lose target)") ~ Dmnl

~ |

"p(incomplete kill)"="p(hit target)"*(1-"p(kill target if hit)") ~ Dmnl

~ |

"p(lose target after miss)"=(1-"p(hit target)")*(1-"p(not lose target)") ~ Dmnl

~ |

Battlefield assessment capacity applied= INTEG (+Change Battlefliedl assessment capacity applied,Reference Battlefield assessment capability) ~ target/Minute

~ |

Battlefield assessment rate=Min(Battlefield assessment capacity applied,Targets in battlefield assessment backlog/Avg Battle assessment duration) ~ target/Minute

~ |

"Cumm Learning Time - acquire targets"= INTEG ("Earn LT - acquire targets",0)

~ LThours

~ |

Spend fire support coordination touch time=(Fire support coordination to asset rate*Mission fraction sent to asset)*Avg Fire support coordination duration*"unit Touch Time hours spent per duration minute (targets)" ~ TThours/minutes

~ |

"Cumm Learning Time - engage targets"= INTEG ("Earn LT - Engage targets",0)

~ LThours

~ |

"Cumm Learning Time - Fire mission development"= INTEG ("Earn LT - Fire mission development", 0) ~ LThours

~ |

Spend target acquisition touch time=(Acquire target completion rate*Mission fraction sent to asset)*Avg Target acquisition duration*"unit Touch Time hours spent per duration minute (targets)" ~ TThours/minutes

~ |

"Cumm Learning Time - Move assets"= INTEG ("Earn LT - Move assets",0)

~ LThours
~ |
Sensitivity of Battlefield assessment capability to Avg Battlefield assessment delay=0.01 ~ ((targets/Minute)/Minute)/Minute

~ |
"Earn LT - acquire targets"=(Acquire target completion rate*Mission fraction sent to asset)*Acquire target unit learning time ~ LThours/Minute

~
"Earn LT - Battlefield assessment"=Battlefield assessment rate*Battle assessment unit learning time ~ LThours/Minute
~ |
"Earn LT - Engage targets"=Engage target rate*Target engagement unit learning time ~ LThours/Minute

~ |
"Productivity - Move assets"=ZIDZ("Cumm Learning Time - Move assets",("Cumm Touch Time - Move assets"*Relative value of LT compared to TT)) ~ Dmnl

~ |
"Earn LT - Fire mission development"=Fire mission completion rate*Fire mission unit learning time ~ LThours/Minute

~ |
"Earn LT - Fire support coordination"=(Fire support coordination to asset rate*Mission fraction sent to asset)*Fire support coordination unit learning time

~ LThours/Minute

~ |
"Cumm Learning Time - Battlefield assessment"= INTEG ("Earn LT - Battlefield assessment",0) ~ LThours

~ |
Reference Battlefield assessment capability=GET XLS CONSTANTS('Input.xls','Input','g5') ~ targets/Minute

~
Relative value of LT compared to TT=1 ~ LThours/TThours
~ |
"Productivity - Engage targets"=ZIDZ("Cumm Learning Time - engage targets",("Cumm Touch Time - Engage targets"*Relative value of LT compared to TT)) ~ Dmnl

~ |

"Productivity - Acquire targets"=ZIDZ("Cumm Learning Time - acquire targets",("Cumm Touch Time - Target acquisition"*Relative value of LT compared to TT)) ~ Dmnl

~ |

"Cumm Learning Time - Fire support coordination"= INTEG ("Earn LT - Fire support coordination",0) ~ LThours

~ |

"Productivity - Fire mission development"=ZIDZ("Cumm Learning Time - Fire mission development",("Cumm Touch time - Fire mission development"*Relative value of LT compared to TT)) ~ Dmnl

~ |

"Productivity - Fire support coordination"=ZIDZ("Cumm Learning Time - Fire support coordination",("Cumm Touch time - Fire support coordination"*Relative value of LT compared to TT)) ~ Dmnl

~ |

"Productivity - Battlefield assessment"=ZIDZ("Cumm Learning Time - Battlefield assessment",("Cumm Touch Time - Battlefield assessment"*Relative value of LT compared to TT)) ~ Dmnl

~ |

"Cumm work cost - Battlefield assessment"="Cumm Touch Time - Battlefield assessment"*"Hourly work cost - Battlefield assessment" ~ kdollars

~ |

"Cumm work cost - Engage target"="Cumm Touch Time - Engage targets"*"Hourly work cost - engage target" ~ kdollars

~ |

"Cumm work cost - fire mission development"="Cumm Touch time - Fire mission development"*"Hourly work cost - Fire mission development" ~ kdollars

~ |

"Cumm work cost - Fire support coordination"="Cumm Touch time - Fire support coordination"*"Hourly work cost - Fire support coordination" ~ kdollars

~ |

"Cumm work cost - Move launchers"="Cumm Touch Time - Move assets"*"Hourly work cost - Move launchers" ~ kdollars

~ |
Cumm Fire mission development $ productivity=ZIDZ("Cumm revenue - Fire mission development","Cumm work cost - fire mission development") ~ Dmnl

~ |
Cumm Fire support coordination $ productivity=ZIDZ("Cumm revenue - Fire support coordination","Cumm work cost - Fire support coordination") ~ Dmnl

~ |
"Earn revenue - engage target"=Engage target rate*"Unit revenue - engage target"

~ kdollars/Minute
~ |
"Hourly work cost - engage target"=GET XLS CONSTANTS('Input.xls','Input','i8')
~ kdollars/TThour
~ |
"Hourly work cost - Fire mission development"=GET XLS CONSTANTS('Input.xls','Input','i6') ~ kdollars/TThour
~ |
"Earn revenue - Move launchers"=Total move asset rate*("Unit revenue - Move launchers"*"Avg no. of targets that each asset can engage at once")

~ kdollars/Minute

~ |
"Hourly work cost - Battlefield assessment"=GET XLS CONSTANTS('Input.xls','Input','i9') ~ kdollars/TThour
~ |
Cumm Battle assessment $ productivity=ZIDZ("Cumm revenue - Battlefield assessment","Cumm work cost - Battlefield assessment") ~ Dmnl

~ |
"Cumm work cost - Acquire target"="Cumm Touch Time - Target acquisition"*"Hourly work cost - Acquire target" ~ kdollars

~ |
Cumm target engagement $ productivity=ZIDZ("Cumm revenue - engage target","Cumm work cost - Engage target") ~ Dmnl

~ |
Cumm Acquire target $ productivity=ZIDZ("Cumm revenue - Acquire target","Cumm work cost - Acquire target") ~ Dmnl

~ |
"Hourly work cost - Fire support coordination"=GET XLS CONSTANTS('Input.xls','Input','i5') ~ kdollars/TThour

~ |

Cumm move launcher $ prodictivity=ZIDZ("Cumm revenue - Move launchers","Cumm work cost - Move launchers") ~ Dmnl

~ |

"Hourly work cost - Move launchers"=GET XLS CONSTANTS('Input.xls','Input','i7')

~ kdollars/TThour

~ |

"Cumm revenue - Acquire target"= INTEG ("Earn revenue - Acquire target",0)

~ kdollars

~ |

"Cumm revenue - Fire mission development"= INTEG ("Earn revenue - Fire mission development", 0) ~ kdollars

~ |

"Cumm revenue - Fire support coordination"= INTEG ("Earn revenue - Fire support coordination",0) ~ kdollars

~ |

"Cumm revenue - Move launchers"= INTEG ("Earn revenue - Move launchers",0)

kdollars

~ |

"Cumm revenue - Battlefield assessment"= INTEG ("Earn revenue - Battlefield assessment",0) ~ kdollars

~ |

"Earn revenue - Acquire target"=Acquire target completion rate*"Unit revenue-Acquire targets" ~ kdollars/Minute

~ |

"Earn revenue - Battlefield assessment"=Battlefield assessment rate*"Unit revenue - battlefield assessment" ~ kdollars/Minute

~ |

"Earn revenue - Fire support coordination"=Fire support coordination to asset rate*"Unit revenue - Fire support coordination" ~ kdollars/Minute

~ |

Total process learning time=Acquire target unit learning time+Battle assessment unit learning time+Target engagement unit learning time+Fire mission unit learning time+Fire support coordination unit learning time+Move asset unit learning time

~ LThours/target

~ |

"Cumm revenue - engage target"= INTEG ("Earn revenue - engage target",0)~ kdollars

~ |

"Revenue fraction - Engage target"=Target engagement unit learning time/Total process learning time ~ Dmnl

~ |

"Hourly work cost - Acquire target"= GET XLS CONSTANTS('Input.xls','Input','i4') ~ kdollars/TThour

~ |

"Revenue fraction - Battlefield assessment"= Battle assessment unit learning time/Total process learning time ~ Dmnl

~ |

"Revenue fraction - Fire mission development"=Fire mission unit learning time/Total process learning time ~ Dmnl

~ |

"Revenue fraction - Fire support coordination"=Fire support coordination unit learning time/Total process learning time ~ Dmnl

~ |

"Revenue fraction - move launchers"=Move asset unit learning time/Total process learning time ~ Dmnl

~ |

"Revenue fraction - Acquire target"= Acquire target unit learning time/Total process learning time ~ Dmnl

~ |

"Unit revenue- Acquire targets"="Revenue fraction - Acquire target"*Unit revenue of process ~ kdollars/target

~ |

"Unit revenue - engage target"="Revenue fraction - Engage target"*Unit revenue of process ~ kdollars/target

~ |

"Unit revenue - Move launchers"="Revenue fraction - move launchers"*Unit revenue of process ~ kdollars/target

~ |

"Unit revenue - battlefield assessment"="Revenue fraction - Battlefield assessment"*Unit revenue of process ~ kdollars/target

~ |

"Unit revenue - Fire support coordination"="Revenue fraction - Fire support coordination"*Unit revenue of process ~ kdollars/target

~ |

Unit revenue of process=1e+006 ~ kdollars/target

~ |

"Unit revenue - Fire mission development"="Revenue fraction - Fire mission development"*Unit revenue of process ~ kdollars/target

~ |

Number of assets applied=GET XLS CONSTANTS('Input.xls','Input','G7')

~ Assets

~ |

Spend battle assessment touch time=Battlefield assessment rate*Avg Battle assessment duration*"unit Touch Time hours spent per duration minute (targets)"

~ TThours/minutes

~ |

"unit Touch Time hours spent per duration minute (targets)"=0.0176667

TThours/(minutes*target) ~ 1 60th of an hour

Total spend move asset touch time="Spend move asset touch time-station to base"+"Spend move asset touch time-base to station" ~

TThours/minutes

~ |

"unit Touch Time hours spent per duration minute (assets)"=0.0176667

~ TThours/(asset*minutes) ~ 1 60th of an hour

|

Target engagement unit learning time=GET XLS CONSTANTS('Input.xls','Input','f8')

~ LThours/target

~ |

"Avg no. of targets that each asset can engage at once"=5 ~ targets/asset

~ |

Acquire target completion rate=Min(Target acquisition capacity applied,Targets being acquired/Avg Target acquisition duration) ~ targets/Minute

~ |

Acquire target unit learning time=GET XLS CONSTANTS('Input.xls','Input','f4')

~ LThours/target

~ |

Battle assessment unit learning time=GET XLS CONSTANTS('Input.xls','Input','f9')

~ LThours/target

~ |

Fire mission unit learning time=GET XLS CONSTANTS('Input.xls','Input','f6')
~ LThours/target
~

Target engagement backlog= INTEG (+Fire mission completion rate+Incomplete kill rate-Engage target rate,0) ~ targets
~ |

Avg time on station=GET XLS CONSTANTS('Input.xls','Input','m5') ~ Minute
~ |

Avg Battle assessment duration=GET XLS CONSTANTS('Input.xls','Input','e9')
~ Minute
~ |

"Cumm Touch Time - Battlefield assessment"= INTEG (Spend battle assessment touch time,0) ~ TThours
~ |

Avg Engagement duration=GET XLS CONSTANTS('Input.xls','Input','e8')
~ Minute
~ |

"Cumm Touch Time - Engage targets"= INTEG (Spend engagement touch time,0)
~ TThours
~ |

Fire mission development capacity applied=GET XLS CONSTANTS('Input.xls','Input','g6') ~ targets/Minute
~ |

Avg Fire mission development duration=GET XLS CONSTANTS('Input.xls','Input','e6') ~ Minute
~ |

"Cumm Touch time - Fire mission development"= INTEG (Spend fire mission development touch time,0) ~ TThours

~ |

Fire support coordination capacity applied=GET XLS CONSTANTS('Input.xls','Input','g5') ~ targets/Minute
~ |

Avg Fire support coordination duration=GET XLS CONSTANTS('Input.xls','Input','e5') ~ Minute
~ |

"Cumm Touch time - Fire support coordination"= INTEG (Spend fire support coordination touch time,0) ~ TThours

~ |

Fire support coordination unit learning time=GET XLS CONSTANTS('Input.xls','Input','f5') ~ LThours/target
~ |

Assets on Station= INTEG (Assets arrive at station rate-Assets leave station for base rate,0) ~ Assets
~ |
Assets in route to Station= INTEG (+Assets leaving base for station rate-Assets arrive at station rate,0) ~ Assets
~ |
Move asset unit learning time=GET XLS CONSTANTS('Input.xls','Input','f7')
~ LThours/target
~ |
"Cumm Touch Time - Move assets"= INTEG (Total spend move asset touch time, 0)
~ TThours
~
Target acquisition capacity applied=GET XLS CONSTANTS('Input.xls','Input','G4')
~ targets/Minute
~ |
Avg Target acquisition duration=GET XLS CONSTANTS('Input.xls','Input','e4')
~ Minute
~ |
"Cumm Touch Time - Target acquisition"= INTEG (Spend target acquisition touch time,0) ~ TThours
~ |

Simulation Control Parameters

FINAL TIME = 900 Minute ~ The final time for the simulation.

INITIAL TIME = 0~ Minute ~ The initial time for the simulation.

SAVEPER = 0.25~ Minute [0,?]~ The frequency with which output is stored.

TIME STEP = 0.125 Minute [0,?]~ The time step for the simulation.

2003 - 2010 Sponsored Research Topics

Acquisition Management

- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- BCA: Contractor vs. Organic Growth
- Defense Industry Consolidation
- EU-US Defense Industrial Relationships
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Managing the Services Supply Chain
- MOSA Contracting Implications
- Portfolio Optimization via KVA + RO
- Private Military Sector
- Software Requirements for OA
- Spiral Development
- Strategy for Defense Acquisition Research
- The Software, Hardware Asset Reuse Enterprise (SHARE) repository

Contract Management

- Commodity Sourcing Strategies
- Contracting Government Procurement Functions
- Contractors in 21st-century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting, Planning and Execution
- Navy Contract Writing Guide
- Past Performance in Source Selection
- Strategic Contingency Contracting
- Transforming DoD Contract Closeout
- USAF Energy Savings Performance Contracts
- USAF IT Commodity Council
- USMC Contingency Contracting

Financial Management

- Acquisitions via Leasing: MPS case
- Budget Scoring
- Budgeting for Capabilities-based Planning
- Capital Budgeting for the DoD
- Energy Saving Contracts/DoD Mobile Assets
- Financing DoD Budget via PPPs
- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-tem Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness

- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)
- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
- Strategic Sourcing

Program Management

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
- Managing the Service Supply Chain
- Measuring Uncertainty in Earned Value
- Organizational Modeling and Simulation
- Public-Private Partnership
- Terminating Your Own Program
- Utilizing Collaborative and Three-dimensional Imaging Technology

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