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Integrating System Dynamics Modeling and Knowledge Value Added for Improved Analysis of Alternatives: A Proof of Concept Study

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Integrating System Dynamics Modeling and Knowledge Value Added for Improved Analysis of Alternatives: A Proof of Concept Study

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Abstract

Effective and efficient DoD acquisition programs require the analysis of a wide range of materiel alternatives. Alternative diversity, 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 AoA, but cost estimates predominate most AoA processes. Incorprating 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 can 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 DoD acquisition processes.

Introduction

The US 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 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 (*CJCSI 3170.01G*, 2009). JCIDS uses Capability Based Assessments (CBA) to validate capability gaps, to discover solutions such as those addressed by non-materiel-type changes to doctrine, organization, training, leadership & 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 where 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) memo, September 19, 2007, Subj: Prototyping and Competition).

System concepts are further clarified during the Materiel Solutions Analysis phase and the accompanying AoA process. As part of these processes, programs move toward several kinds of evaluative cost comparisons that formulate costs estimates across a notional life cycle. 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; 2009, May 13-14; 2009, July). 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 the production costs, and, beyond that, all of the operating costs of spares, diagnostics, maintenance, tools, training manuals, etc., must be estimated.

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. In current guidance (e.g., the GAO's Cost Estimation Guide, 2009, p. 35) 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/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 third author's experience 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) become a metric of program life and death, but with notably sparse articulation of empirical benefit to the customer/end user.

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 1987-89,the US 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 replace its aging and ineffective DRAGON weapon system. Principally, the weapon was to do the following: be able 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 be able to engage armored vehicles under cover or in hull defilade. The US 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 man-in-loop throughout its rapid flight. It was cheapest at an estimated $90,000 “cost per kill,” a figure comprised not only of average production unit cost estimates but also reliability and accuracy estimates. It was fairly effective in terms of potential combat utility, with diminishing probability-of-hit at increasing range.
- The Hughes/Boeing Fiber-Optic guided prototype enabled an unexposed gunner (once launched) and also required 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 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, was perceived as both costliest and technologically riskiest. It would be easiest to train and would be 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 the government acquirers and program sponsors. All three candidate teams engaged with finally 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 the winner of the COEA, presumably from weighted cost/efficiency factors. But in a strange twist, the concurrent deliberation of the Source Selection Evaluation Board (SSEB) instead chose the FLIR candidate, presumably because of a bias toward “fire & 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 of 1989 to the Joint Venture team of Texas Instruments and Martin-Marietta. However, at about 18 months into this program, serious technical problems doubled the expected cost of development and added about eighteen more months to the originally planned thirty-six months to complete. This constituted a Nunn-McCurdy breach of cost and schedule thresholds, with requisite Congressional notifications and formal re-baselining 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 re-evaluate 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 OSD 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 $90K "cost per kill" as had been estimated for the laser beam-rider, then the program should be terminated and re-started, 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 micro-chips 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 produce 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 $12k being the target for average UPC, given a planned buy quantity of about 70,000. And cost of 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 FPAs—a very unusual move by sponsors, having 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 re-baselined 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

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

component. After still more and difficult advanced development program challenges, AAWS-M eventually became the Javelin—and is known today as one of our most successful combat systems. (In the end, soldiers and Marines never had to accept to accept B and C-level FPA performance, as 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, and 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 is 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 benefits 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:

- Examine how military operations systems dynamics 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 US 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 ROI2) 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:

- *Clinger-Cohen Act of 1996* that mandates the assessment of the cost benefits for information technology investments.
- Government Accountability Office's *Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making*, Version 1, (February 1997) that requires that IT investments apply ROI measures.
- *DoD Directive 8115.01*, issued October 2005, that mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments.
- *DoD Risk Management Guidance Defense Acquisition* guide book that requires alternatives to the traditional cost 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 a 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.

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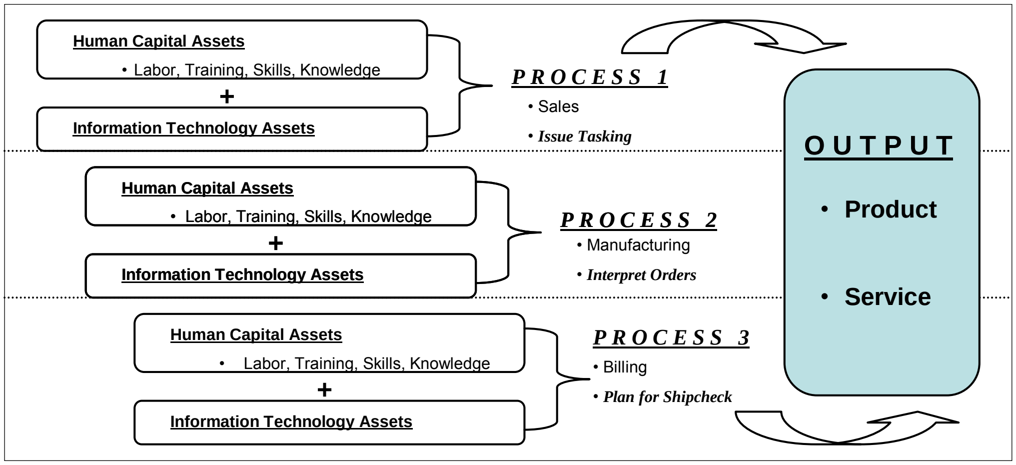
[2] ROI is defined as the revenue-cost/cost where revenue is defined as the price per common unit of benefit using a market comparables approach. Given that the price per common unit is a constant, precision in estimating the market comparable price, i.e., revenue, is not required.



Measuring Output

For the purpose of the systems dynamics model developed for this study, KVA was used 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. KVA was used to measure the value added by the human capital assets (i.e., military personnel executing the processes) and the system assets by analyzing the processes performances. KVA provided a means to set the systems dynamic model parameters so that the results would provide a means 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 support 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 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:

- 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 cost of producing those outputs in common units.

Describing processes in common units also permits, but does not require, market comparable data to be generated, particularly important for non-profits like the US 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 non-profits. 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 sub-organizational level. KVA can rank processes or process alternatives by their relative ROIs. This assists decision-makers in identifying how much 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, 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.

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; Lane & Jackson, 1995; Jackson, 2003). Forrester (1961) develops the methodology's philosophy, and Sterman (2000) specifies the modeling process with examples and describes 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, 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 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.

Based on the preceding 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, Knowledge Value Added and system dynamics were integrated to test their ability to improve the precision of AoAs in acquisition programs. A generic structure of a mobile weapon system process was first developed and tested using the system dynamics methodology. Then, KVA value and cost estimates were operationalized in the system dynamics model. The model was calibrated to reflect four extant weaponized Unmanned Aerial Vehicles (UAVs). One of those calibrations was used as the basis for using the model in a hypothetical AoA for upgrading the UAV to address a different type of target. Simulation results were analyzed 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.

A Generic Model of Mobile Weapons Use

The model has three sectors: weapons movement, target evolution, and KVA analysis. As will be described, 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). It is assumed that the total number of assets remains constant, i.e., no weapons are 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 doing, 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.

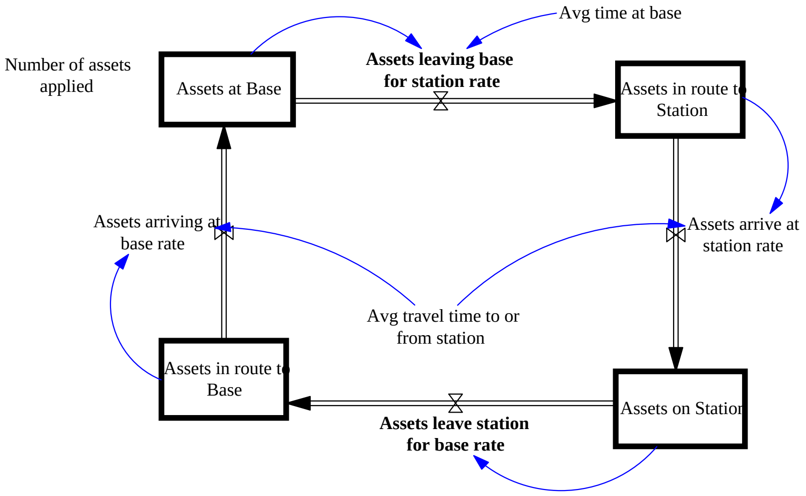


Figure 1. Positions and Movement of Weapons during Operations

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 (Lombardo, 2003; 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 doctrine, major systems, significant capabilities and limitations and often their TTP [tactics, techniques and procedures] (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 doing, and require processing time to complete. Therefore, they are each outputs of those subprocesses and inputs to the KVA analysis.

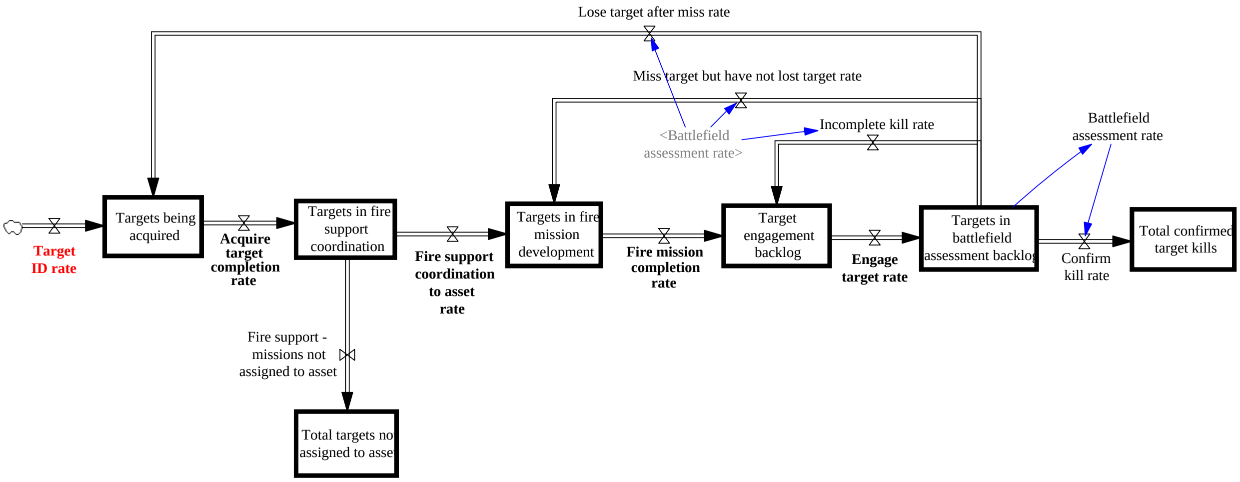


Figure 2. Accumulations and Movements of Targets in Weapon System Operations

In addition to the primary flows of targets through the subprocesses, the targets 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 targets 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 with 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 model use section of this report describes how these features of the model were used to describe operational scenarios and weapon configurations. The fraction of the targets that are returned due to being hit but not destroyed (to engagement backlog), missed (to mission development backlog), or lost (to target acquisition backlog) battlefield assessment rate 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] The probabilities are determined by comparing the ability of a weapon to successfully destroy, hit, and not lose targets to the characteristics of the target and a function that describes how the weapon's ability compared to the target impacts weapon performance. 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 then the closer it can get to the target before releasing ordinance, increasing the 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 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 weapon speed far exceeds target

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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, facilitate intuitive understanding of the model.

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

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 be aggregated. At each point in time, each subprocess's productivity is the benefits it has generated divided by the costs to generate those benefits (i.e., output/input).The model includes both monetized and time-based KVA metrics. However, it was 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 the output (i.e., common units of learning time)/input (cost to produce the outputs) standard definition of productivity.

A time-based application of KVA uses Learning Time to quantify benefits and Touch Time to quantify costs. Learning time captures the benefits derived from human processing (e.g., flying the vehicle), automated processes (e.g., take offs and landings), and (importantly) technologies integrated into the weapon. 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.

The denominator of KVA subprocess productivity ratios represents subprocess costs. Each subprocess is assigned a Unit Touch Time that reflects the relative (compared to other subprocesses) effort required to perform 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:

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

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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 Model Use section of this report.

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 to estimate the productivity or the entire operation. This allows the comparison of different asset configurations (alternatives).

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
6. battlefield assessments

Three of the four actual UAVs are operational: Predator, Sky Warrior, and Reaper. The fourth UAV is the X-47B. Basic characteristics relating to performance were collected for the four UAVs from publicly available sources (e.g., Global Security, 2010). That information included vehicle range, total mission time, time on station, dash speed, and payload. In some cases, multiple versions of the vehicle with different characteristics have been developed. 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, such as that the time required to engage a target after arriving on station is inversely proportional to the vehicle’s dash speed (i.e., faster dash speeds reduce the time required to engage). These estimates are rough, but adequate for this proof-of-concept study, which seeks to determine if the model is capable of reflecting differences in characteristics in KVA parameters, not predict 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 on previously validated models, the literature improves the model’s structural similarity to actual acquisition projects, as practiced. Model behavior (e.g., simulated sizes of backlogs for subprocesses and rates of performing operations) were compared to typical behavior and found to be similar. For example, before operations start at the beginning of the operational scenario (described in what follows) the backlogs are empty and no operations are being performed. The appearance of targets increases subprocess backlogs and rates of operation as weapons leave base and subsequently arrive on station, targets are acquired, fire coordinated, missions developed, targets engaged, and the battlefield assessed.

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) change weapon availability. Model behavior was also tested with extreme input values such as perfect operations (e.g., probability of hit=100%) and very large versus very small number of weapons and targets as well as more typical conditions. Model behavior remained defensible across wide ranges of input values, including extreme values. These tests increase confidence that the model generates realistic operational process 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 400-1100nm. This describes targets that range from being closer to the weapon’s base than the shortest weapon’s range to targets that are 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 describes targets that range from those that are immobile to targets that are faster than the fastest weapon. 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 describes targets that range from being very soft to very hardened.

KVA productivities for the six subprocesses and the cumulative for those processes for the four Weaponized UAVs are shown in Table 1. For example, the KVA productivity ratios for the Fire Mission Development subprocess for the four UAV 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 of the return on the investment, in percent. These values remain constant in the model after steady state operations have 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 5 hours of operations) of 79,684 learning-time hours and 84.5 processing-time hours. In the simulated steady state operations this accumulated learning time hours increases 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 increases 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., start or end of operations) or other non-steady state operations can generate ratios that vary over time.

Table 1. KVA Productivity Ratios

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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 to include dynamic variation in the entering target rate, distributions of target characteristics, and more target characteristics.

		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 above, 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 are not impacted by the characteristics of the vehicle (Acquire targets Fire support coordination, and Battlefield assessment) do not change. These subprocesses are not impacted by different vehicles because the subprocess is 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 do impact total product productivity ("Weapons" row in Table 1) do vary (Fire mission development, Move weapons, and Engage targets).

Some of the ratios in Table 1 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, fire support coordinated, fire mission developed, and the UAV moved to station. Actual engagement times are relatively short for these UAV, further increasing the KVA productivity ratios for the engage target subprocess. Differences in learning-times across the UAV reflect their relative performance (e.g., automation of subprocesses previously performed by humans) and technologies are the primary causes of differences in the ratios across UAV in Table 1. Therefore, it is reasonable that the very large benefits of the under-development X-47B with its extremely advanced technology generate the largest ratios. Improved estimates of learning-times and processing times can improve the accuracy of these ratios. However, comparing the KVA productivity ratios for the engage targets subprocess with the ratios for the move weapons subprocess that 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.

Using System Dynamics and KVA to Improve AoA

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, but 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 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 impacts 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] as follows:

- **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 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 increases the time that the vehicle is on station and available for missions.

Performing detailed analysis of all the possible alternatives, such as by building and testing prototypes or very detailed simulations, often exceeds the resources of acquisition programs. Therefore, program managers are 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 provided 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, first the operation of the system with each potential alternative is simulated and the simulation model is used to calculate the KVA productivity ratios for the subprocesses and system as a whole. Table 2 provides an example of a portion of such an analysis for the hypothetical upgrading of the Predator UAV using the model described above.

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

Table 2. Predator UAV Upgrade Program KVA Productivity Ratios for Analysis of Alternatives

		Subprocess KVA ratios			Weapon System	
		Develop fire mission	Move weapons	Engage targets	KVA ratio	% Change from Base Case
	Predator Base Case	943	50	5,094	705	0.0%
Improvement Alternative	**Increase fuel capacity 100%**	**1,886**	50	5,094	**951**	**34.9%**
	Increase fuel capacity 50%	1,415	50	5,094	831	17.9%
	Increase Power plant 100% for payload	849	50	7,641	771	9.4%
	Increase Power plant 50% for payload	849	50	7,641	771	9.4%
	Redesign transmission for 100% faster dash speed	943	**100**	**10,188**	741	5.1%
	Redesign transmission for 50% faster dash speed	943	75	7,641	727	3.1%
	Increase Power plant 100% for dash speed	849	**100**	**10,188**	717	1.7%
	Increase Power plant 50% for dash speed	849	75	7,641	702	-0.4%
	Reduce time at base 50%	943	52	5,094	699	-0.9%
	Reduce time at base 100%	943	51	5,094	695	-1.4%

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 KVA+SD modeling results are adequate to show how more accurate results might be used in an AoA of these potential capabilities upgrades. Based on the results above, a program manager can assess the relative value-added of the eleven alternatives (including no-change as reflected by the Base Case) analyzed. Comparison to the base case (e.g., the existing vehicle in the case of the Predator upgrade) provides an estimate of relative performance improvement. Sorting the improvements provided by potential alternatives in decreasing order (Table 2) lists 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, 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 delete reducing time at the base and a 50% increase in power plant capacity that is used to increase dash speed from consideration since 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.

Discussion and Conclusions

Summary

The Knowledge Value Added (KVA) approach to including benefits in 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 systems. A hypothetical upgrade program to one of the UAV 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 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 2) 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, based on the right-hand column, Table 2 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 2 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 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 2 indicates that the *reason* increasing fuel capacity improves performance is 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 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 potential and selected alternatives through their impacts on specific subprocesses and operations to performance.

- Justifications of 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 above. This will generate more effective and potentially cheaper materiel solutions.

In addition, improving AoA and acquisition through integrated system dynamics/KVA models can improve CONOPS. The Javelin case study described previously in this report provides a vivid example of the ability of acquisition in general and improved AoA such as through integrated system dynamics/KVA modeling 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, can generate changes to strategies. Accurate forecasts of product subprocess performance (e.g., accuracy at longer range) can 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 is 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 and 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 Analysis of Alternatives and acquisition. Additional research can extend this work toward implementation and expanded application. Opportunities include:

- 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 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 life cycle 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 life cycle.

The Analysis of Alternatives is a particularly challenging part of DoD acquisition. Integrating system dynamics modeling and the Knowledge 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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- 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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