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Extending an Econophysics Value Model for Early Developmental Program Performance Prediction and Assessment

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Abstract

This study is focused on presenting the viability of an econophysics theory of value as a means for creating a quantitative value metric to estimate the future value of Department of Defense (DoD) technology acquisition programs. We will describe a simple value model and further definitize this model into a DoD acquisition framework to illustrate the utility for developmental programs within the DoD and defense industrial base. This paper will describe a method by which a metric for surrogate financial value can be allocated across a program, allowing program managers to assess the surrogate return on investment (s-ROI) of their programs and providing greater flexibility in managing program risk. Additionally, we introduce a new program performance index that reflects s-ROI which incorporates a risk-based measure that modifies and extends the traditional earned value management (EVM) cost and schedule indices and provides an earlier indication of program challenges. We refer to this index as the s-ROI Performance Index (RPI), which has the potential of being a leading program indicator on overall program value and performance. Recommendations for the use of this model in DoD acquisitions, in general, are provided at the conclusion of this study.

Introduction

The research problem is that the Department of Defense (DoD) is not able to predict the **value** to risk relationship of technology acquisitions under development. Current metrics used in DoD acquisition programs are not sufficient to adequately predict program performance early enough for decision makers to objectively influence program outcomes. DoD programs tend to be managed using cost as an independent variable (CAIV), limiting the program managers' (PMs') flexibility with regard to managing risk. Exacerbating this problem is the lack of quantitative economically based value metrics for use in estimating the future value of DoD acquisition programs[1]. This leaves the PM to focus on cost growth, often at the expense of system performance capabilities. Additionally, the primary index by which PMs gain insight into cost variance is through EVM cost and schedule indices, which tend to be lagging indicators due to the latency in the data and the lack of predictive power on future performance. Hence, the PM is driven to making performance trades to reduce cost growth at the expense of capabilities.

When there is no unique quantitative value metric with which to take advantage of commonly used financial ratios, such as ROI, the PM is forced to use metrics that do not have the predictive power because they lack insight into the value per unit cost being realized in the program. As a performance measure, ROI is useful in evaluating the efficiency of an investment or to compare the efficiencies of several different investments ("Return on Investment," n.d.).

When these ratio estimates are properly constituted, the PM can make more accurate predictions of the future value of product/service acquisitions, leading to more informed investment trades between cost and the value of operational capabilities. These summary performance ratios are useful in making defensible investment decisions because they are broadly accepted and can be used to feed a more sophisticated analysis for investment/acquisition decision making, such as portfolio optimization and real options analysis (Mun, Housel, & Wessman, 2010). Additionally, predicting the value performance of DoD technology acquisitions is necessary in optimizing acquisition investment portfolios before further investments in the more codified, restrictive acquisition stages.

The purpose of this study is to extend the econophysics model to the DoD acquisition program life cycle in order to create a practical quantitative value metric that can be used to better understand and predict the s-ROI estimates of an acquisition program prior to contract award and to provide an early indicator of program performance during program execution. This is important because predicting the quantitative value of future DoD technology programs, prior to contract award, will allow for a more productive use of DoD investments. Additionally, gaining early insight into program performance will mitigate cost and schedule variance throughout the program development phase of the acquisition life

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[1] Any form of cost will not provide a unique value metric. Measures of cost savings, while useful in evaluating investments in technology, do not provide unique value metrics. For example, if the numerator of a return on investment or cost/benefits ratio is cost savings, then the astute investor would fire everyone and sell all the tangible assets, producing an infinite return with cost savings in the numerator and zero in the denominator. Value estimates must be made independent of cost estimates to ensure a legitimate performance ratio.

cycle. This insight will allow DoD decision-makers to more clearly understand the risk and reward of future systems.

This study applies the econophysics model (Housel, Baer, & Mun, 2015; Baer & Housel, 2016; Baer, Bounfour, & Housel, in press) to generate estimates of the financial value of a given DoD technology investment. We use a basic example to explain the relationships between theoretical physics principles and economic measures frameworks. Our example presents the basic concepts using an applications (app) program for the DoD and relates the variables to a more traditional program acquisitions strategy.

The literature is replete with cost studies describing the cost analysis and program measurement milestones process. Much of this research is retrospective in nature and attempts to use historical data to predict future performance using models that focus exclusively on cost and schedule. Over the past 13 years of the Acquisition Research Program annual symposium, there have been numerous studies of how to estimate acquisition program costs, from activity-based costing to earned value measurement (EVM). In spite of these substantial research efforts, no widely accepted method for estimating costs has won out over all the others. None of these methods has proven to be exceptionally insightful with regard to predicting actual program life-cycle costs or performance with any degree of certainty. The lack of viable cost data prior to program start and no quantitative predictable value data by which to compare with program cost estimates has left decision-makers even more challenged in making reasonable forecasts based on economic program performance. By applying a surrogate measure of revenue to the same cost centers measured by EVM, a value metric can be used to assess overall program performance. This paper will address this gap in literature with regard to value estimation within a system's developmental program life cycle. Ultimately, this approach can be used across many industries and program contexts.

EVM is the program performance model most often used for major defense programs. The name of the model suggests that actual value is being measured, but from an economic perspective, this view would be incorrect. In effect, EVM is a cost model based upon prior cost and schedule predictions. Ultimately, this approach does not make predictions or assess whether the investment in a program, during the development life cycle, yields reasonable returns that are worth the investments in systems. Essentially, the DoD has no idea how much quantitative value it is getting from the investment of a dollar into a program of record under development.

The premise of the current research is that not having an accepted quantitative revenue estimate precludes program managers and program milestone decision authorities (MDAs) from making decisions that are based on a program's projections of overall value within threshold and objective cost boundaries. In order to accurately assess value and the resulting s-ROI, a quantitative surrogate revenue estimate needs to be allocated across a program in addition to the allocation of cost for the program. During the development of the performance measurement baseline, financial value needs to be allocated at the same level of detail as program cost allocation estimates. This would allow PMs to more effectively manage risk and make program decisions within the value and cost trade space.

Previous research on value-based management (VBM) suggested that having an unambiguous quantitative value metric would allow decision-makers to measure the performance of their company from a value maximization perspective, which is the ultimate economic objective for an organization. Since traditional financial performance measures, such as earnings or earnings growth, are not always good proxies for value creation, VBM focused more on the value creation process. Organizations tend to set goals in terms of discounted cash flow (DCF) value, the most direct measure of value creation. VBM takes this a step further by requiring targets to be translated into shorter-term, more objective financial performance targets (Koller, 1994). While this approach begins to address the issue of assessing program performance relative to value creation, it does not go far enough in identifying a commonly unitized measure for value. It simply requires that **qualitative** metrics be established by which an organization can measure “goodness” of performance. These value metrics are not normalized with a common unit of value measure that can be quantitatively compared to cost and subsequent ROI estimates.

Additionally, the lack of a common quantitative surrogate revenue parameter (i.e., quantitative value parameter) that is not directly derived from the cost estimate means that costs cannot be compared across a portfolio of project investments. In turn, the ROI of a portfolio of projects cannot be determined since there is no unitized value metric by which cost can be compared. ROI is a ratio of revenue to cost as expressed in Equation 1.

$$\text{ROI} = [(\text{Revenue} - \text{Cost})/\text{Cost}] * 100 \tag{1}$$

Absent a definitive measure for revenue, a portfolio is simply a conglomeration of costs that provide little insight into whether the portfolio is actually worth the overall investment relative to the portfolio forecasts. From a DoD acquisition perspective, this means that investments in enterprise program organizations are measured against cost and the relative qualitative estimates of the utility these programs provide for the customer. While some may argue that the economic value of a system lies in the operational utility of that system, without a common unit measure of surrogate revenue and therefore ROI, the customer might be overpaying for the expected utility and subsequently impacting the overall operational environment in which the system will operate. By having a higher ROI per system, the DoD will be in a better position to allocate scarce resources across a much larger portfolio of warfighting capability.

The search for a practical value metric has been going on for some time in the field of economics. Interfield theory provides an interesting opportunity for investigating the viability of other scientific theories and principles that might be applied to the field of economics. In the history of economics and physics, economists borrowed the energy concept from physics to develop value theories (Beinhocker, 2006; Mirowski, 1989). The econophysics model used in this study will take advantage of this mapping of energy theory from physics to develop a quantitative value estimate for the pre-contract award of DoD acquisition programs. This interfield approach to developing a methodology for quantitatively measuring value is consistent with many fields that use analogic extensions of physics models. This analogic reasoning is useful in developing more analytical and testable theory propositions (Kuhn, 1970). The mapping of physics-based terms to economic concepts, and subsequently to defense acquisition programmatic concepts, requires a proof of concept modeling demonstration case to test the viability and practicality of the derived value metric. Such a metric must be defensible as well as useful to acquisition professionals when generating investment productivity ratios such as ROI, which is an elegant, intuitively appealing productivity ratio and is applicable across acquisition portfolios.

The value theory demonstrated in this research will bear directly on public procurement policy and management as well as contracting and program/project management. Additionally, the application of value theory within program management introduces information sciences concepts, in that we are dealing with the collection and analysis of critical information within management, physics, and social sciences paradigms. From a policy perspective, this theory will provide a new measure by which to assess the relative value of warfighting systems compared to other system investment options. By understanding the ROI of acquisition programs and comparing them on a portfolio basis, more informed economic trades can be made relative to their overall perceived operationally valued utility. Additionally, at the program level, contracting and program managers' decision-making will be aided by having a robust estimate of the economic value of a given acquisition/procurement over time to compare to the investment costs of the program. Given the extreme riskiness of investments in programs such as information technology, acquisition executives would benefit from a clear understanding of the investment to performance productivity ROI, risk-reward ratios that a system will have over time, and whether that investment return is acceptable.

Research Questions and Objectives

This research addressed the following research questions:

1. Can an econophysics value theory model be used to predict the value of a proof-of-concept pre-contract award technology acquisition in the DoD?
2. How might an econophysics value theory model be used in a DoD acquisition context to aid in investment decisions?

The objective of this study is to test the use of an econophysics value theory model to create a defensible value metric that can be used to predict the performance of future DoD acquisitions in order to optimize acquisition investment portfolios.

Methodology

In what follows, we will provide a rationale and method for identifying and measuring non-monetized quantitative surrogate financial value. We label this value "proto-value" or prototype value (PV) metric. Our econophysics framework identifies the production of proto-value using analogies to a comprehensive physics conceptual model. This model is operationalized using PV calculations for which the case examples provide estimates for the model parameters. By establishing proto-value as a surrogate for allocated revenue, we are able to definitize the required parameters for a surrogate ROI (s-ROI) term in an acquisition program. Plotted over the life of the program, s-ROI reflects the baseline of investment return expected for the program.

The s-ROI performance measurement baseline (PMB) is analogous to the EVM PMB in that it provides a measure of work accomplished over time. However, while the EVM PMB measures the cost of work over time, the s-ROI PMB measures the expected value of the investment relative to the level of effort over time informed by a risk metric. For each increment in time, the s-ROI PMB will provide the decision-maker a unit of value relative to investment cost and risk, providing a more informed measure by which the program can be evaluated for relative worth and practicality. With a surrogate value for revenue, the s-ROI PMB can be operationalized at the work breakdown structure cost center level. Similar to the EVM PMB, the s-ROI PMB will provide indices of performance such as cost performance index (CPI), s-ROI performance index (RPI), and schedule performance index (SPI). Current EVM indices only provide CPI and SPI and provide no analytical index for the quantitative value of the program, whereas RPI provides an additional metric based upon value rather than just cost and risk. CPI and SPI are calculated using Equations 2 and 3, which are based on standard EVM calculation methodologies.

$$\mathrm{CPI} = \mathrm{BCWP}/\mathrm{ACWP} \tag{2}$$

$$\mathrm{SPI} = \mathrm{BCWP}/\mathrm{BCWS} \tag{3}$$

Where

BCWP – Budgeted cost of work performed

ACWP – Actual cost of work performed

BCWS – Budgeted cost of work scheduled

Since RPI is a function of surrogate revenue expressed in terms of proto-value, it may be expressed in the following terms:

$$\mathrm{RPI} = [(\mathrm{PV})(\mathrm{BCWS}) - \mathrm{ACWP}]/\mathrm{ACWP} \quad (4)$$

where

PV – Proto-value is a non-dimensional value representing allocated surrogate revenue allocated throughout the program work breakdown structure.

The existing econophysics model uses terms from physics to define relationships between individuals and processes in an economic supply and demand framework. Terms such as mass and distance are used to explain product performance and quality as well as the level of consumer attraction toward the product in the context of distance. The consumer attraction toward a product is defined in DoD requirements documents such as the Capability Development Document (CDD), which specifies the systems requirements and critical attributes. These attributes represent the level of demand or attraction the DoD user has toward the specific requirement. Critical attributes with the highest demand are delineated as Key Performance Parameters (KPP) which specify both threshold and objective values that must be met by the program manager of the system under development. If a system under development is close to the objective for the KPP, then the distance between the operational user (consumer) is very small. However, if the system under development is closer to the threshold, then the distance between the user and the product is larger. If the system is below the threshold, then the distance between the user or customer and the product under development approaches infinity.

A fitness matrix can be subsequently generated to map customer need vectors to program value vectors within the context of the relative distance (e.g., cost, ease of use, riskiness) between the two. Additionally, a series of non-linear matrices with associated first order derivatives can be developed that reflect the changing nature of the variables that affect the need and value vectors between the customer and the product. For a DoD program, these derivatives are representative of the vast number of variables that might affect the relationship between the requirement and the intended capability to be provided by a contractor. For DoD acquisition programs, these vectors and derivatives are extracted from requirements documents such as the CDD, program acquisition strategy (AS), technical proposals, proposal evaluations, and cost documentation. Additionally, intervening processes that might affect the AS could be considered in the establishment of derivatives that might impact the relative attraction between a user need and the prospective capability that satisfies that need. During the pre-contract award phase, the relative value of multiple offers from various vendors in industry can be used to compare the value of satisfying the specified requirements in the government request for proposal (RFP), thereby quantitatively establishing priorities in order to forecast the financial value impact of cost, schedule, and requirements changes during contract management of the program life cycle.

In the context of a non-monetized quantitative value theory, there was a need to create new categories for common units of value. One promising common unit candidate for proto-value is a unit of complexity (Housel & Kanevsky, 1995; Housel & Bell, 2001). Complexity theory has been touted as foundational for a new theory of economics

(Beinhocker, 2006) even though this prior work did not posit a unit of complexity as central to this argument. Our analysis offers a physics-based framework where we rely on the concepts of mass, potential field, force, momentum, velocity, total energy, and work extracted from total energy. In the example that follows, we have aggregated a number of the physics concepts into a simplified form to show how it is possible to use the resulting framework for a rough-cut analysis of the velocity of adoption rate of the information technology (IT). Table 1 shows the relationship between physics variables and organizational variables.

Table 1. Concept Definitions

mass {**m**} = relative richness of services, measured in common units of complexity. Richness refers to the desirability and perceived availability of a product, capability, or service.
Position of m = name of node in a network of the entity that is offering the service established by the force of the pull of the business and the pull of the customer for the service
Force = the pull of the mass of the company {**Mb**} – the pull of the client mass {**Mc**} (**Force = m*Mc/r**^{2} **[distance squared] * K (constant) or client desire/r**^{2}**)**
Business Mass {**Mb**} has a given strength of pull on the service {m}
Client Mass {**Mc**} pull on the service offered by the business
Number of services {**N**} = total number of {**m**} services at a given point in time (e.g., email, search)
Total Potential Field (TPF) ≈ (**m*Mc*N/distance between the Mc and Mb**) the number of services of a given complexity (m) offered by an organization to a field of potential clients (TPF = total proto-value field)
Velocity (V) = Change in rate of position of **m**
Momentum {Mo} = rate at which service {m} moves from Mb to Mc
TPF*Mo = total Energy (E) ≈ proto-value
Work = total actual value extracted from proto-value

Conceptual Example

In order to better understand the aforementioned concepts, we present a simplified example with a subsequent alignment to the broader DoD acquisition environment. The simplified model uses an example of a pre-award IT contract for a defense intelligence community service program. A quantitative proto-value estimate was derived for this example program by applying the concepts defined in the econophysics model. Throughout this example, we will further definitize the terms in order to explain their association with other DoD developmental programs. Additionally, we will show how this approach is a viable strategy for developing a predictive model to assess the s-ROI PMB and subsequent value targets that are informed by not only cost, but also surrogate revenue and risk.

In this example, the acquisition leadership wished to take advantage of the potential social media apps (i.e., defined as Facebook + Twitter + Snapchat). Table 2 is a summary of the key econophysics terms that we use to demonstrate how our interfield theory approach to economics and program management can be used to better understand program performance through other disciplines such as physics.

Table 2. Framework for Simple Model to Estimate the Proto-Value of a Pre-Award Contract

	mass {**m**} = The term mass is typically used when describing a property of a physical body. It also refers to the strength of the gravitational forces between bodies. We similarly use mass to reflect the relative complexity between services, which is a direct analogy to the strength of ties between the various services or products and their intended user.
	Number of apps (**N**) = total number of apps (or products) at a given point in time (i.e., email, texting, image sharing). This is essentially, the number of capabilities being provided by the developer at a specific point in the schedule of the program.
	Potential Field (**PF**) = (**m*N**) the number of apps of a given complexity (m) offered by the organization to a field of customers/clients/users
	Velocity = Rate of **PF** over time period of three years

Mass

In this notional example of the simplified econophysics model, operationally defining mass was done using an interval complexity scale. There are several options for operationalizing mass as delineated in Table 1. The definition of mass depends on the context of the model. Several possibilities, when considering options for defining mass for the simplified model, include

- a 1–10 complexity interval scale
- a more detailed ratio level scale (e.g., lines of code [bits], embedded algorithms)
- a knowledge-based estimate (e.g., amount of knowledge embedded in the IT [learning time] created from intellectual-social capital

Additionally, mass within the context of a more traditional DoD program can be operationalized through interval scales of complexity such as Technology Readiness Levels (TRLs) or other similar complexity scales that rate the level of complexity or richness of specific requirements within the CDD. These scales provide the relevant level of readiness of the desired requirement being asked for by the user and translates into mass within the tenets of the econophysics theory. A useful tool for assessing technology complexity is the TRL assessment rating scale described in Figure 1.

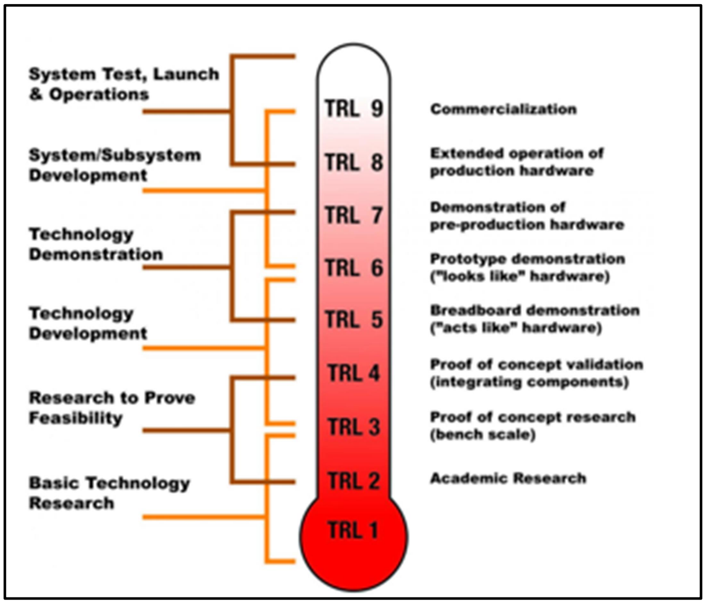

Figure 1. Technology Readiness Level Descriptions
(DoD Technology Readiness Assessment Guide)

The TRL level describes a standard by which the technology should be measured in terms of its readiness to be accepted by the user. The higher the TRL, the more ready the technology is for operational use and the more mass the requirement has from the users' perspective.

Potential Field

Potential field (PF), in the current example, is represented by the number of potential modified social media apps that would be acquired and offered to a given field of user groups. For example, in the case of Facebook, it would be represented as all the modified apps that would be produced and offered to its user groups. Potential Field would be quantified as the total number of modified apps (that had a given mass measurement) offered to the potential user groups at a given point in time.

Within the broader DoD perspective, the PF represents the total number of capabilities (N) the contractor offers in response to a government RFP times the relative mass of these capabilities. The RFP specifies the requirements being asked for by the user and the relative performance, or mass, required to meet these requirements. If the contractor offers all of the capabilities being asked for by the government, the PF would be 100%. times the mass of the capability, as defined previously.

Work

Estimating the amount of work that can be extracted from the total potential proto-value (total potential energy) in the simplified model can be represented as the actual usage of the modified apps by the user groups. This part of the simplified model becomes useful once the apps are offered to the user groups. It then becomes possible to determine the yield rate from potential to actual usage (i.e., amount of realized proto-value, kinetic energy).

Simplified Framework for Estimating Proto-Value and Work

Continuing with our simplified example, DoD acquisition leadership would like a quick, rough-cut estimate of the yield of proto-value from actual usage (i.e., amount of realized proto-value or work) from the apps over a three-year actual adoption rate time period. This provides a means to compare the expected actual adoption rate to the potential adoption rate (calibrated in terms of proto-value) to determine the accuracy of the forecasts for the program. Estimates of potential proto-value over the three-year period provide an estimate of the modified apps adoption rate calibrated in terms of potential value to the user groups. The realized proto-value of the apps provides a measure of the actual value to the user groups calibrated in terms of their usage of the apps over the three-year period. The simple model estimates are summarized in Table 3: Customer Usage of Modified Social Media App Offerings. This kind of adoption rate information provides a means of measuring the value yield of these apps that allows an assessment of the accuracy of the adoption rate forecasts.

Table 3. Customer Usage of Modified Social Media App Offerings

Number of potential uses of apps proto-value (PP) (based on potential uses of the modified apps within the three-year projected adoption rate time-frame)
Number of realized proto-value of the apps (RP) (e.g., based on number of actual downloads, clicks, page views within the time frame of the availability of the modified apps)
PP * PF = Proto-value = total potential energy
RP * PF = Realized Proto-value ≈ Work

The **RP** metric includes how many times users actually used the apps that have a given mass. The equation **RP * PF** can be used to derive the measure of the yield extracted from **PP**. The difference between **PP** and **RP** also provides a measure of the unused capacity of the modified apps represented as the opportunities foregone to provide value to the user groups. Using the example of the modified social media apps adoption rate, we can generate a table of values that will allow a yield estimate based on results per Table 4.

Table 4. Modified Social Media Apps Example

Year	Potential User Groups	Actual Adoption of Apps by User Groups	PF (from Table 2)	PP	RP
2010	100	40	168	16800	6720
2011	120	60	284	34080	17040
2012	125	90	248	31000	22320
Totals	**345**	**190**	**700**	**81880**	**46080**
				Yield =	56%

Comparing total PP with RP provides a simple yield ratio of 46,080/81,880 or 56% yield for the three-year period. This value yield could be compared with industry averages for this kind of modified social media app as well as for other IT acquisitions cases. These yields comparisons might be very useful for acquisition leaders, as well as user group leaders, in tracking the conversion PP to RP performance.

In this example, the acquisition leadership wanted to estimate how rapidly the potential social media apps, modified for use by service member organizations, would be adopted. The estimate included the number of new social media services that are rolled out to the potential user groups. Included in the estimate is the relative mass (measured in terms of relative complexity on a 1–10 scale) of the app modifications. The velocity (i.e., change in forecasted adoption rate) of the modified apps is presumed to be a reasonable surrogate for predicting the future adoption rate of these apps by potential user organizations. The total potential proto-value is estimated in terms of the total potential energy field times the number of potential user organizations that might adopt the modified social media apps. For a more traditional developmental program that provides either a product or service, the potential proto-value would equate to the number of requirements in terms of products or services expected to be used by the user times the total number of capabilities being delivered by the respective contractor.

Table 5 is a summary of the potential adoption rate example and reflects the kind of data this simplified model would generate. It is based on the expectations of the planned acquisitions of these modified apps over a three-year period. In this example, the expectation is that the number of modified apps for two of the social media apps (i.e., T and S) will diminish in Year 3. This reduction in introduction of new modifications directly affects the potential adoption of these apps even though the number of user groups is expected to grow. After rising from Year 1 to Year 2, this drop in new modifications is reflected in Figure 2, which indicates that the adoption rate velocity of the modified social media apps should be falling precipitously from Year 2 to Year 3.

Table 5. Potential Adoption Rate Example

Year	Facebook (FB) **8*N**	Twitter (T) **6*N**	Snapchat (S) **4* N**	PF **FB+T+S**	V	Potential Users Organizations (PU)	Total Potential Energy Field **PF*PU**
2015	56	12	100	168	90	100	16800
2016	80	24	180	284	116	120	34080
2017	80	18	150	248	-36	125	31000
Totals	216	54	430	700		345	81880

Mass per service weightings
FB = 8 T = 6 S = 4

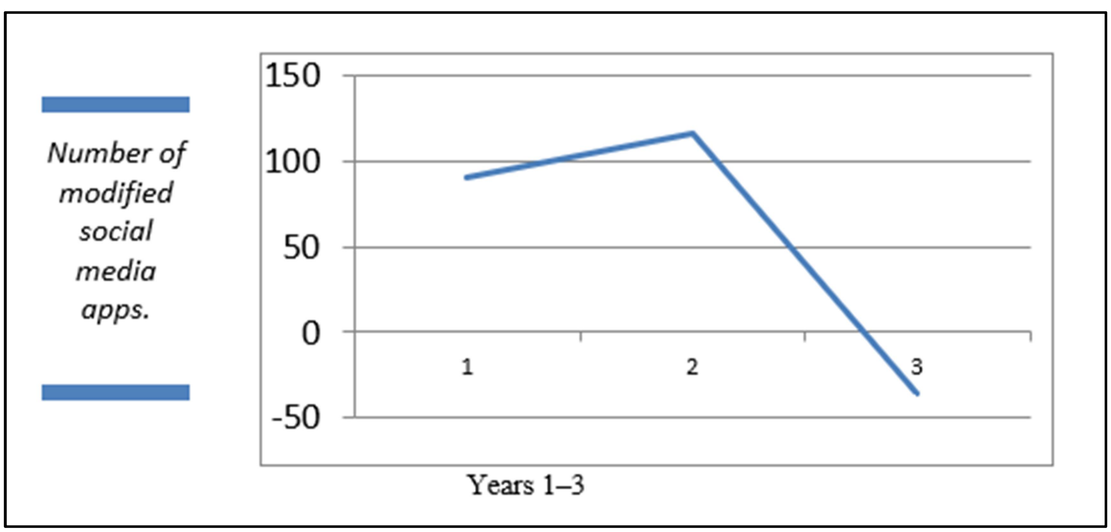

Figure 2. Potential Adoption Rate Velocity

This drop in potential proto-value, even with the increase in potential user groups, should provide a rationale to advocate for continued increases in development of modified social media apps or set expectations that there will be a potential reduction in the proto-value of these apps due to the reduction in investments in the modifications of the apps. One implication from the use of this simplified model for the adoption rate velocity estimate is that there is a correlation between the velocity of potential adoption of new social media apps and the proto-value of these apps. Increasing the velocity of introduction of modified apps would represent an increasingly larger potential field for customers, while decreasing velocity would represent an overall reduction of potential proto-value due to the decreasing number of modified apps being offered to the potential user groups. One can see that increasing the number of apps is only one way that the potential proto-value can be increased. It would also be possible to increase potential proto-value in a given year by offering the modified apps to a larger number of potential user groups. The goal of this example is to demonstrate a simplified way to forecast the potential proto-value of information technology investments.

Defense Acquisition Framework

While the preceding example begins to explain the relationships between econophysics and proto-value with regard to services-based applications, a more rigorous explanation of how these principles relate to more established developmental program business processes is necessary. We will introduce the concept of risk and probability of success to the model and show how significant these concepts are in predicting program performance. By introducing proto-value and risk, we will show how program performance prediction is significantly more reliable than traditional methods using forms of cost as the sole metrics.

Table 6 relates the econophysics terms defined for the simplified program example with a more generic defense acquisition program. Risk is introduced with regard to the probability of success (Ps) of meeting specified requirements defined by the operational user and articulated in the Capabilities Development Document (CDD).

Table 6. Framework for Simple Model to Estimate the Proto-Value of a Contract Pre-Award Modified for Standard DoD Acquisition Program

mass {**m**} = relative complexity of key performance parameters (KPP) as defined in the Capabilities Development Document (CDD) multiplied by its Technology Readiness Level (TRL) (Scale of 1–9, as defined in Figure 1)
Number of capabilities (**N**) = number of completed capability solutions in the contract relative to the proposed contractor schedule that supports meeting the KPPs
Potential Field (**PF**) = (**m*N**) the number of capabilities of a given complexity (m) offered by the contractor in the contract proposal
Velocity = Change in rate of **PF** over time period of contract performance
Probability of Success (P_s) = (1-%risk) of completing a specified requirement defined in the CDD where %risk is shown as; **r.** Therefore **P_s = (1-r)**
(PP) - Number of potential requirements **(R)** multiplied by the probability of Success – **[R*(P_s)]**
Realized Proto-value (RP) – number of requirements actually accomplished in the contract relative to the CDD and proposed schedule

Understanding risk is necessary for determining the probability of success for a particular program and, subsequently, the proto-value. Risk is the principle indicator as to whether a program will succeed. Program managers and decision-makers must make informed decisions prior to contract award based upon TRL and the overall risk of accomplishing the various requirements for the program. While risk is considered in current source selection processes, it is not integrated into a probability of success calculation that reflects the potential program's return on investment. Risk is typically managed as a separate entity concurrently with cost and schedule. While risk is derived from the same data by which cost information is collected, the integration of risk into the program performance calculations is not well developed. Consequently, risk is simply characterized as a qualitative function based upon subjective methods in determining the potential cost and schedule impacts a given contractor might experience throughout the program life cycle. The risk matrix shown in Figure 3 is a standard model that is explained in the DoD Risk Management Guide and is typically used in most programs within the DoD and industry.

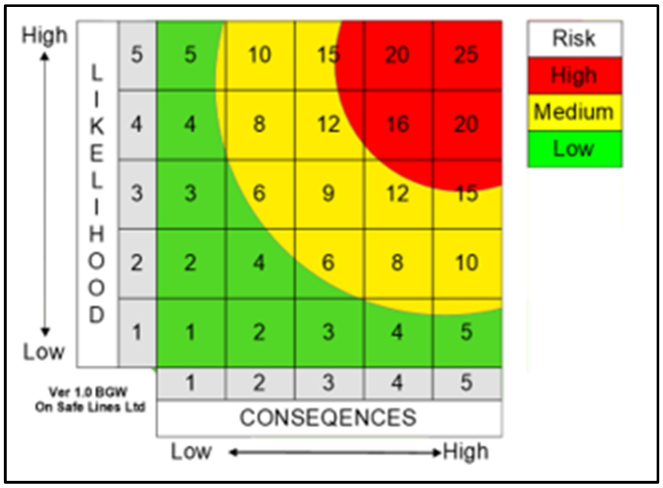

Figure 3. Standard Risk Matrix
(DoD Risk Management Guide)

This process determines the likelihood and consequence of realizing a risk and is reported to the program manager on a regular basis. Done correctly, potential risks are identified through the requirements analysis process, during which the requirements are decomposed into subordinate tasks. This process allows the program manager to allocate a cost and schedule risk to the individual requirements and subsequently to the overall program. The problem with this method, however, lies in the absence of translating risk into potential success and s-ROI. Intuitively, program managers feel that if they sufficiently mitigate the risk at the predetermined time identified in the risk management process, then this will result in a lower likelihood of cost and schedule creep. This says nothing about potential for actually succeeding and maximizing the surrogate financial return on investment relative to the operational utility of the system being developed. The goal of this research is to tie the potential for program success to operational utility by showing how s-ROI is a better measure of program performance than traditional cost methods. For the purpose of this research, we are using a surrogate measure for ROI derived from proto-value.

Using risk as a basis for understanding the potential for success, we have redefined the traditional risk matrix in terms of the probability of either meeting or not a meeting the specified requirements defined in the CDD. While these percentages are debatable, they simply reflect the logic of the argument. Table 7 reflects the likelihood and consequence of not realizing the completion of a particular defined requirement listed in the CDD, which is important in determining the overall value of the program.

Table 7. Percent Risk of ***Not*** Completing an Individual Requirement Defined in the CDD and the Relative Consequence of Not Completing the Requirement

High	60	70	80	90	100
High	50	60	70	80	90
Medium	40	50	60	70	80
Medium	30	40	50	60	70
Low	10	20	40	50	60
Low	Low	Medium	Medium	High	High

Return on Investment Performance Index (RPI) Comparison With Earned Value Cost and Schedule Indices (CPI/SPI)

Major defense programs and large commercial programs typically use EVM metrics to measure their performance. These data are generally historical in nature and require the program manager to extrapolate future performance based on program risk and other mitigating factors. While this is a good measure of tracking pre-contract award cost to work relationships, it does not provide an early assessment of program value relative to the potential for program success. Consequently, programs tend to get into trouble earlier than program managers are able to observe through traditional measures, and program managers are unable to ascertain the relative program performance based upon investments. If there were a way to inform the program manager on how a program was performing relative to the investment, decision-makers would be able to make decisions as to the program net value rather than simply falling victim to making cost and performance trades based upon increasing cost and schedule.

Using the principles of econophysics and basic EVM methods described previously, we are able to show that s-ROI is a better predictor of program performance than traditional EVM metrics alone and is referred to as s-ROI Performance Indicator (RPI) in subsequent discussions. By way of summary and explanation, the following equations show how each of the variables in Table 8 were derived for a notional developmental program with a 36-month expected period of performance.

BCWS – Performance Measurement Baseline and Cumulative Program Cost over the period of performance

BCWP – Budgeted Cost of Work Performed is the cost per unit of work budgeted at the start of the program

ACWP – Actual Cost of Work Performed is the actual cost charged by the contractor

R – Specified requirements that are identified in the CDD

N – Number of capabilities completed by the contractor over time

P_s – Probability of Success – (1-%risk) = (1-r); r = f(cost, schedule, TRL)

PF – Potential Field – (m*N)

PV – Proto-value (surrogate term for revenue). This term is non-dimensional for the purpose of our calculation of RPI.

PP – the number of potential user specified requirements multiplied by P_s

With this as a summary, the relevant equations follow:

$$\text{CPI} = \text{BCWP}/\text{ACWP} \tag{5}$$

$$\text{SPI} = \text{BCWP}/\text{BCWS} \tag{6}$$

$$\text{RPI} = [(\text{PV})(\text{BCWS})] - \text{ACWP}/\text{ACWP} \tag{7}$$

Where

$$\text{PV} = \text{PP} * \text{PF} \tag{8}$$

$$\text{PV} = (\text{R} * \text{P}_\text{s})(\text{m} * \text{N}) = ([\text{R} * (1 - \text{r})])(\text{m} * \text{N}) \tag{9}$$

Table 8 shows the contractor is expected to perform $10 worth of work every month for 36 months with the overall PMB reflected in the BCWS column. This baseline is developed using typical EVM methods, the process of which is defined in standard EVM textbooks.

The data in Table 8 reflects a program with some amount of anticipated risk with regard to developmental maturity. The risk is informed by the TRL level of the program and is considered in the calculation of the monthly and overall potential field (PF) (that also includes mass per requirement number) for the program. Generally, the program reflects a user requirement for 10 “needs” at a cost of $10/month for 36 months. The data in Table 8 reflects a delta between the Budget at Complete and the Actual at Complete to be $43, representing an overall cost variance of 11%. By Month 21, the program seems to be costing more than expected, and by Month 23, the program seems to be producing less output (i.e., value) per unit cost than expected as shown by the increase to an ACWP of $11 from an expected ACWP of $10 and decrease from $10 BCWP to $9 BCWP, indicating that there is less output than expected for that point in the schedule.

Typically, a program begins to suffer technical problems before these would be reflected in EVM cost reports. EVM does not provide an early warning signal of technical issues because of the lagging nature of EVM data. Using the econophysics model, this early indication of a technical problem is seen in the decrease in PF from 10 to 8 and a monthly decrease in PV from 90 to 72 at Month 19. This is realistic in that technical issues generally reveal themselves earlier in the process than they are reflected in the lagging indicators of EVM data. Using the equations defined previously for PV and RPI, a plot of PV relative to EVM data is shown in Figures 4 and 5. The cumulative PV shows a rate change as early as six months prior to the first significant indicator of a problem using EVM data. The first sign of trouble in EVM is the CPI at Month 24 and the second is SPI at Month 28, whereas RPI begins to inform the situation as early as Month 19.

Table 8. Notional Program EVM and Proto-Value Data

Month	Cost Est/ Mo	BCWS	BCWP/mo	BCWP	ACWP/mo	ACWP	R	Ps	PF	PV per Month	Cum PV	RPI	CPI	SPI
1	10	10	10	10	10	10	10	0.9	10	90	90	8.9	1	1
2	10	20	10	20	10	20	10	0.9	10	90	180	8.9	1	1
3	10	30	10	30	10	30	10	0.9	10	90	270	8.9	1	1
4	10	40	10	40	10	40	10	0.9	10	90	360	8.9	1	1
5	10	50	10	50	10	50	10	0.9	10	90	450	8.9	1	1
6	10	60	10	60	10	60	10	0.9	10	90	540	8.9	1	1
7	10	70	10	70	10	70	10	0.9	10	90	630	8.9	1	1
8	10	80	10	80	10	80	10	0.9	10	90	720	8.9	1	1
9	10	90	10	90	10	90	10	0.9	10	90	810	8.9	1	1
10	10	100	10	100	10	100	10	0.9	10	90	900	8.9	1	1
11	10	110	10	110	10	110	10	0.9	10	90	990	8.9	1	1
12	10	120	10	120	10	120	10	0.9	10	90	1080	8.9	1	1
13	10	130	10	130	10	130	10	0.9	10	90	1170	8.9	1	1
14	10	140	10	140	10	140	10	0.9	10	90	1260	8.9	1	1
15	10	150	10	150	10	150	10	0.9	10	90	1350	8.9	1	1
16	10	160	10	160	10	160	10	0.9	10	90	1440	8.9	1	1
17	10	170	10	170	10	170	10	0.9	10	90	1530	8.9	1	1
18	10	180	10	180	10	180	10	0.9	10	90	1620	8.9	1	1
19	10	190	10	190	10	190	10	0.9	8	72	1692	7.1	1	1
20	10	200	10	200	10	200	10	0.8	8	64	1756	6.3	1	1
21	10	210	10	210	10	210	10	0.8	8	64	1820	6.3	1	1
22	10	220	10	220	11	221	10	0.8	8	64	1884	5.7181818	0.909	1
23	10	230	10	230	11	232	10	0.8	8	64	1948	5.7181818	0.909	1
24	10	240	9	239	11	243	10	0.7	8	56	2004	4.9909091	0.818	0.9
25	10	250	9	248	11	254	10	0.7	7	49	2053	4.3545455	0.818	0.9
26	10	260	9	257	12	266	10	0.7	7	49	2102	3.9833333	0.75	0.9
27	10	270	8	265	12	278	10	0.7	7	49	2151	3.9833333	0.667	0.8
28	10	280	8	273	12	290	10	0.7	7	49	2200	3.9833333	0.667	0.8
29	10	290	8	281	12	302	10	0.7	7	49	2249	3.9833333	0.667	0.8
30	10	300	8	289	14	316	10	0.7	7	49	2298	3.4	0.571	0.8
31	10	310	7	296	14	330	10	0.7	7	49	2347	3.4	0.5	0.7
32	10	320	7	303	14	344	10	0.6	7	42	2389	2.9	0.5	0.7
33	10	330	7	310	14	358	10	0.6	7	42	2431	2.9	0.5	0.7
34	10	340	7	317	15	373	10	0.6	7	42	2473	2.7	0.467	0.7
35	10	350	7	324	15	388	10	0.6	7	42	2515	2.7	0.467	0.7
36	10	360	7	331	15	403	10	0.5	6	30	2545	1.9	0.467	0.7

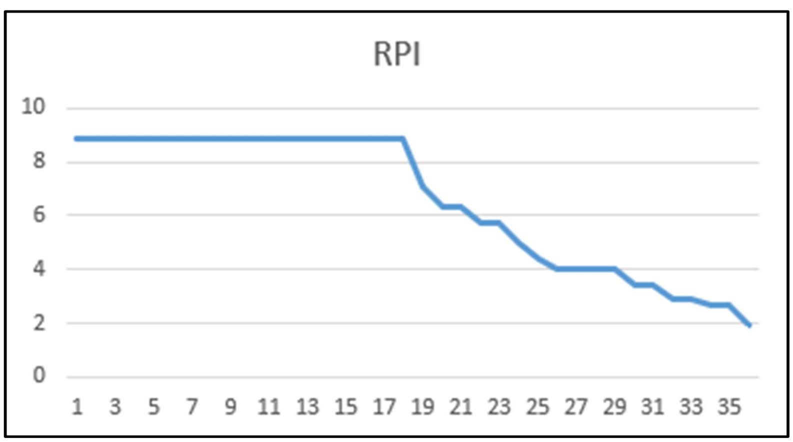

Figure 4. Program s-ROI Performance Index (RPI)

Figure 5 is another view of the same data using CPI and SPI as the performance indices. Comparing Figures 4 and 5, RMI begins to fall off much earlier than CPI and SPI. This is explained by the fact that risk and probability of success are incorporated into the PV calculation. Additionally, PF impacts the overall PV in that we are assuming in this basic example that mass does not increase significantly and N begins to drop by Month 19. This is fairly typical in programs in that contractor performance issues are first observed in technical performance, indicating a schedule impact. The value N is a function of schedule, leading us to conclude that N would be an early indicator of performance as the contractor begins to fall behind in completing tasks, followed quickly by cost (ACWP).

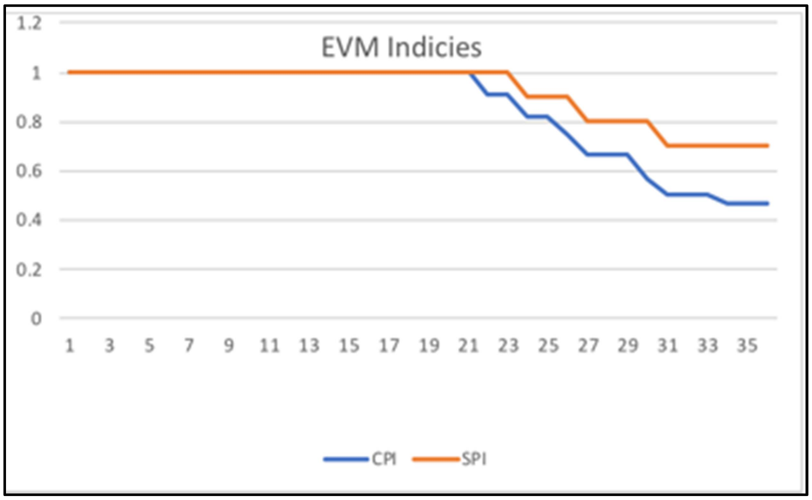

Figure 5. EVM CPI/SPI Indices

The data shows that establishing a measure for value based upon revenue will inform the decision-maker when a program ROI is decreasing. This decrease in ROI, as reflected in the RPI, can be an early indicator of program issues. Since the RPI is directly influenced by risk, the lag typically associated with EVM data is mitigated. Knowing that a program is attaining less value for its investment is a powerful measure by which leaders can make informed decisions regarding the viability of a program.

Potential Benefits

The results of this study provide a methodology for estimating a surrogate for financial value of a given technology at the pre-contract review stage of an acquisition program. Current methods used to predict program performance are based upon techniques such as EVM, which helps project managers to measure project performance. It is a systematic project management process used to find variances in projects based on the comparison of work performed and work planned. The EVM process establishes a Performance Measurement Baseline (PMB) which provides a baseline by which the contractor is measured. The PMB is a time–phased schedule of all the work to be performed, the budgeted cost for this work, and the organizational elements that produce the deliverables from this work. This baseline is agreed upon prior to contract award by the government and subsequently included in the statement of work for the contract.

While the PMB is an attempt to estimate cost over time, it provides no assessment of the financial value of the program and subsequent ROI. Furthermore, the cost estimates used to determine the PMB are typically based on incomplete information due to the program risk uncertainty. Development programs typically use cost reimbursable type contracts which attempt to account for unknowns due to technology immaturity and overall program risk.

Once the contract is awarded, actual performance is measured against the PMB. With near certainty, all DoD programs tend to breach the PMB, leading to either a rebaseline or termination. A better measure of program performance is ROI. By establishing an ROI baseline, the desired ROI is measured over time, allowing decision-makers to focus their decisions on how to optimize program performance by balancing risk and proto-value. Rather than chasing costs, which inevitably increase due to risk and other programmatic influencers, increasing costs become less critical if they are measured against value and subsequent ROI. If the ROI of a program remains within predetermined thresholds, the PM can allow cost to “float,” within reason, and offset this with increased efficiency, resulting in higher ROI. Essentially, the program manager can set cost threshold and objective limits in order to establish budget constraints but will manage to the ROI baseline vice the cost baseline. This method would allow the program manger more flexibility in developing innovating strategies and managing risk that are based upon value rather than simply focusing on cost. Cost as an independent variable (CAIV) would be replaced with ROI and an independent variable (RAIV).

Acquisition leadership should find the simplified econophysics and more complex model useful in the pre-award acquisition phases in estimating whether an IT investment has promise based on its potential value (i.e., proto-value) compared with other options. Continuous estimates of the proto-value, after an acquisition, should prove useful in attempting to improve the fitness and reduce the distance of the acquired IT. For these reasons, the econophysics models should help improve acquisition investment portfolios. Use of these models should also provide the acquisition leadership a way to track the use of their investments to avoid costly mistakes.

Conclusions

These examples of how the econophysics approach can be used to model the potential value of new or mature products or services demonstrated that (when the data values can be verified) it is possible to predict the potential value of the acquisition of a new or mature product or service. The purpose of this study was to demonstrate that it is possible to use econophysics formalisms to model the potential proto-value of new products and services before their acquisition in a pre-award phase. These estimates can be routinely updated during the product/service adoption rate life cycle, as well as when modified or discontinued. The econophysics approach can be combined with existing investment tools and approaches to create more accurate potential value estimates before services or products are acquired.

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