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GAP ANALYSIS: RETHINKING THE CONCEPTUAL FOUNDATIONS

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Gap Analysis: Rethinking the Conceptual Foundations

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Abstract

Gap Analysis is widely regarded as a useful tool to facilitate commercial and defense system acquisitions. This paper is a rethinking of the theoretical foundations and systematics of Gap Analysis with practical extensions to illustrate its utility and limitations. It also provides a new perspective on those theoretical foundations from the perspectives of systems and value engineering.

The growing sophistication and complexity of new systems or system-of-systems have resulted in a dramatic increase in time and money to reach operational capability. Gap Analysis, properly defined and enacted, clarifies goals, appropriate investment and the end-use.

Introduction

The challenge of successfully acquiring and operating a new system is to ensure that the mission will be accomplished within an acceptable level of loss. To that end, there have been numerous attempts to develop and field systems that are intended to prevail in the event of conflict. How should these future systems be defined? Who is responsible? What processes guide the system requirements? If "we" perceive a deficiency or a desired goal that is different from that which we are intending, then there could exist a basis for gap in capability and, therefore, a desire to close the capability gap.

What one desires versus what one has is, in essence, a Gap. The Gap is as much the relationship between what is perceived to be *important* and the derived difference between performance and expectations. The methodology and analysis of that difference is the descriptive foundation for Gap Analysis. From a mission-capability perspective, a Gap may consist of deficiencies in operational concepts, current or projected operational disadvantages, technologies, and understood future needs. To be specific, a Gap must be founded on the starting and ending points as well as the difference between these points. Quantifying these metrics typically involves evaluating a number of situations and mission scenarios in concert with actions or, more generally stated, guidance from policy and goals. Measures of Effectiveness (MOEs) have long formed the set of standards from which to determine how well a capability satisfies a requirement (Sproles, 2002). MOEs are distinguishable from Measures of Performance (MOPs) in that MOEs offer the external view, while MOPs are more consistent with the internal view. The external view captures the system's beginning and ending points, and the MOE of the candidate programs to fill the gap. The internal view involves measures of how well one fills the gap through the MOPs. Therefore, one must formulate both MOEs and MOPs to fully define a Gap. However, Chairman of the Joint Chiefs of Staff Instruction *CJCSI 3170.01D*, *Joint Capabilities Integration and Development System* (2004, March 12) focuses on MOEs, yet does not mention MOPs. There is an implied admixture of MOEs and MOPs defined as MOEs, but the essential qualities of performance-based metrics are missing for carrying out activities and actions, for measuring functions, and from which to determine economic and numeric losses.

Gap Analysis is deeply embedded and fully institutionalized as a cornerstone of the United States Department of Defense (DoD) acquisition strategy, particularly in the critical process called Valuation of Alternative (VoA), formerly Analysis of Alternatives (AoA). It is the purpose of Gap Analysis within the DoD VoA process to report on the evaluation of the performance, operational effectiveness, operational suitability, and estimated costs of the alternative systems to meet a desired mission capability. In this context, the VoA assesses the advantages and disadvantages of alternatives under consideration.

The goal of Department of Defense (DoD) Gap Analysis is to compare current capability to a set of requirements. Where differences arise, gaps are identified and quantified, and mitigations are prioritized and planned. This paper addresses the theoretical foundations and systematics of Gap Analysis with extensions to illustrate its utility as a useful management tool for both defense and commercial acquisition purposes. Without a considered theoretical foundation from which to conduct Gap Analysis, an inadequate level of guidance regarding appropriate methodology and analytical methods may well result. The metrics of Gap Analysis are defined on the basis of system value (Langford, 2006; Langford & Huynh, 2007) and assessed risks.

Discussion

For the US Department of Defense (DoD), the acquisition of goods and services follows the policies outlined in Directives, the Joint Capabilities Integration and Development System (JCIDS), and the Defense Acquisition Guidebook *DoD 5000* (the structure and operation of the defense acquisition system). In this context, Gap Analysis is a method for identifying the degree to which a current system satisfies a set of requirements. The goal of Gap Analysis is to align an anticipated future outcome with a future reality that can be formulated, definitized, and established or constructed. However, Gap Analysis is not intended to close the space between the most distant extremes or the rarest occurrences. Rather, Gap Analysis is centered on the larger, more general aspects that are by and large not part of the present reality (referred to as the current reference frame). For the DoD, Gap Analysis grew out of the realization that relying solely on a threat-based approach (used as a primary driver of requirements until 2000) or a technology approach to determining future needs is both costly and largely ineffective. One of the concerns with threat-based methods lies with the notion of being guided by the will and intentions of others (e.g., adversaries) (as exemplified through an analysis of threats, their efficacy and robustness), rather than relying on our competitive advantages to define and frame future engagements.

Alternatively, a technology-centered approach is open-ended, with little constraint for what can be postulated. Acquisitions based on a technology approach may not result in a continuous presentation of appropriate military hardware that is consistent with lifecycle cost issues or the necessary capabilities in time of conflict. With only theoretical physics as the constraint, technology developments can extend twenty years or longer (e.g., ground-based, airborne, and space-based laser weapon systems). Even with an incremental approach to delivering products, usable incarnations of systems may be distanced by inadequacies in the phases of development and levels of integration. At issue is the availability of weapons systems and doctrine that can prevail in hostilities without: (1) spending an enormous amount of money to sustain existing systems until new systems are delivered, and (2) having to develop a *needed* technology engineered and made available for use. Acquisitions based on a threat-based approach are always plagued by the credibility of the threat—the absolute measure of what an adversary will have available in the future.

Accordingly, neither the technology nor the threat-based approaches address some of the persistent, perennial issues that fundamentally impact the implementations of Gap Analysis.

Since the turn of the century, the DoD has concentrated on a capabilities-based approach, in which capabilities are defined and identified using a top-down approach infused with characteristics of measures of effectiveness, supportability, time, distance, effect (including scale) and obstacles to overcome. Capability is defined by an operational user as the ability to execute a specified course of action (CJCS, 2004).

Gap Analysis Background

The first reference to Gap Analysis was in the 1938 publication on the disjuncture between cultural goals and institutional norms (Merton, 1938). The notion was adapted to psychotic behavior (1950s), preferred biodiversity (1980s), personnel planning (1989), and more recently, competitive analysis and interest rates of financial instruments. Gap Analysis was referred to in a series of instructions from the Chairman of the Joint Chiefs of Staff throughout the 1990s with reference to defining gaps in capabilities requiring a material solution. In the late 1990s, the DoD infused a form of Gap Analysis into the acquisition process—comparing future threat-based assessments to current capability. Meanwhile, program costs seemed out of control; major projects were cancelled, and functionality was not being delivered as desired. A memorandum from Secretary of Defense Donald Rumsfeld asked for ideas to fix the DoD process of determining system requirements (Rumsfeld, 2001). Gap Analysis had come into being and was thriving within the structure of the JCIDS process. The determinant factor for acquisition had moved from a threat-based premise to a capabilities-based identification of needs. While the threat continues to be a part of the acquisition process, part of the initial capabilities document (ICD)—the document that initiates the acquisition system management process—Gap Analysis is performed on the basis of desired capability.

While Gap Analysis should be neither technology-driven nor threat-driven, it is an approach that largely uses technology and threats as inputs to a vision-driven future. Gap Analysis is based on the high-level collective vision of *what we need*. This vision is discussed at the top levels of government within the context of the national security strategy: the strategic concepts postured for defense, the joint operations concepts, and the integrated architectures of US forces. The vision is then stated as a goal, one that is to be achieved methodically through a step-wise process. The problems with the existing formulation of Gap Analysis are determining: (1) what constitutes the foundation data, (2) which data are relevant to a future competitive analysis, (3) how should the relevant data be structured to deal with the future issues within the proper context, (4) what are the assumptions and scaling rules used to extend the current state of industrial output, technology advances, and engineering developments, and (5) what process or methodology enforces consistency of performing Gap Analysis.

Research Objectives

The process of identifying needs and unsatisfied desires, or gaps in capability—in essence, the goal—is sometimes enacted through a set of ad-hoc processes and actions accompanied by an analysis of alternatives. Closing the capability gap between what exists and what is wanted includes the aptitude required to develop something new and the reference point from which one starts. This is an Omni-dimensional problem that encompasses strategy, operations, systems engineering processes, and the compositional elements of the system. Technology readiness and maturity are integral parts of Gap Analysis.

The first step in improving Gap Analysis is to determine the underlying premises and fundamental metrics of such an Analysis. This paper investigates the theoretical issues of Gap Analysis and proposes seven metrics based on quantifiable worth, value, and risk. By developing the theory of Gap Analysis into a form that can be applied in a clear and consistent manner to the DoD acquisition process, we can directly apply the process of defining requirements. Specifically, Worth metrics can be applied to a critical examination of foundation data; Risk metrics can be used to interpret the relevancy of data; an Enterprise Framework (which displays Worth and Risk metrics) can illustrate context at a given time; and assumptions can be definitively scrutinized. To further understand and determine the applicability of Gap Analysis for DoD acquisition, a final step in this work is to identify the general limitations of Gap Analysis and the general impositions that Gap Analysis places on the success of the acquisition process.

Theory

Gaps have to do with mechanical causal histories—the telelogic argument that gaps exist and can be ameliorated by goal-directed actions. Aristotle was the first philosopher to formulate an accountable theory of telelogy founded on four causal properties: material, formal, efficient, and final. He argued that these four causes are required to give a complete account of any event. The cause of material involves being made of matter (e.g., the product); the cause of formal involves relations between entities (e.g., the network); the cause of efficient involves acting in certain ways (e.g., the procedures); and the cause of final involves having specific goals towards which actions are directed (e.g., the use) (Aristotle, 350 B.C.E.).

For the Department of Defense, Gaps are defined in terms of functional areas, relevant span and domain of military operations, intended effects, temporal matters, policy implications and constraints. Further, all gaps are defined in terms of capability. The Joint Capabilities Integration Development System (JCIDS—the formal US DoD procedure which defines acquisition requirements and develops the criteria to evaluate weapon systems) was implemented to specifically address capability gaps. But not all capability gaps require a material solution set. Changes or enactments of Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, and Facilities (DOTMLPF) are also considered to close Gaps. Such considerations are formally evaluated before recommending the start of a new acquisition effort (CJCS, 2004; CJCS, 2005). In essence, functional capabilities are assessed to identify gaps.

It is relevant to mention the pioneering work by Lawrence Miles (1972) to formally recognize and focus attention on functions of a product. Product functions create (or cause) performances relative to investment. The ratio of performance to investment is a measure of relevancy and effectiveness.

Yet Gap Analysis is concerned with the difference between the present and the future, the reality and the expected, but not with the time or discrete time-steps between these disparities. While the DoD typically formulates its development interests in a temporal domain (e.g., a timeline of activities), the development activities are construed and managed as a discrete set of events. The Systems Engineering Process Models reinforce the notion of when to move from one stage of product development to the next stage, as well as what tasks need to be completed within each stage. Consequently, the notion of a temporal juxtaposition of activities is less relevant to the event-driven outcomes that characterize a future competitive space. In other words, Gap Analysis does not reflect when something will actually happen, only that it will happen. This defining of a Gap (in a different way than found in US acquisition policy, *DoD 5000 series)* lends itself naturally to a display of intentions that accurately reflect the constraints of event-based competition founded on the product, operations, and strategy of the various competitors.

In total, this redacting of Gap Analysis into events rather than timelines eliminates the actual propositional attributes of the competition, but retains the notional attributes. Propositional attributes iterate the validity of belief attitudes (i.e., I know what I know; I know what I want). Notional attributes include intentions and wishes (i.e., the end result is not influenced by the proposer's illative skills) (Duzi, 2002). Temporal considerations (e.g., I know when I want it) can be added as an attribute of the Enterprise Framework after the researcher gains an understanding of the situational awareness in event-space (a structure and analysis formed without temporal constraints). There are alternative interpretations of Enterprise Frameworks, most notably for software applications (Hafedh, Fayad, Brugali, Hamu & Dori, 2002). This study maintains that such theories can be used to surmise a means to enforce consistency in process, application, and interpretation of Gaps.

Value

The prime distinguishing characteristic of Value Engineering is the use of functional (or function) analysis (Miles, 1972, first published 1961). Value Engineering (VE) was developed by Miles and Erlicher at General Electric in 1947 as a means recognize and explore what an element of the system does rather than what it is. Value Engineering is an organized process to optimize a system's functionality versus cost. Alternatively, VE provides the necessary functions at the lowest cost, or determines which alternative design will provide the most reliable performance for a given cost. In essence, analyzing Value is the way and manner of analyzing productivity, selecting alternatives, and otherwise manipulating the ratio of Performance to Cost. For the purpose of this report, the authors will not distinguish between Value Engineering and Value Analysis. Value Analysis (VA) is typically concerned with productivity, the use of labor, materials and profitability.

The term Value has many colloquial definitions, including the term's use and misuse often disguised as promoting various marketing and sales concepts. But in the main, constructs of Value are without merit and meaning unless there is a relationship to functions, and therefore by reference, to system objective(s) or use(s). Value is not synonymous with cost or investment. Value is the functionality and performance of a system divided by the investment to deliver or sustain that system (Langford, 2006; 2007). Further, Value is not Worth, which is a measure of Value given risk (discussed in next section). There are different types of Value (use, esteem, cost, exchange, scrap, and so forth). For the purposes of this report, the authors do distinguish between the types of Value.

Value compares the functionality and use one receives versus what one invested (Langford, 2006). This notion of Value explicitly requires a buyer and seller model to determine Value. This presupposes that there is always a “source and a sink,” an “input and an output,” a pre-condition and a post-condition that is the determinant of Value. Therefore, Value is the ratio of the defining characteristics of the product (Functions and Performances) divided by the investment to achieve that functionality and performance. Value is measured in absolute terms. For example, the product shall provide a function with a specified performance. That function does 0.5 of what was paid for (as perceived from the point of view of the developer). Or perhaps, the performance was measured at 90% of the requirement. The investment expended to achieve that functionality and performance was as planned. Therefore, the value was less than desired (developer’s perspective). The *Value Function* (Equation 1) relates the System Value to the System Use(s) or to the System function(s) and performances related to the functions, divided by the investment.

Equation 1.

$$V(t) = \frac{\sum \{F(t) * P(t)\}}{I(t)}$$

where $F(t)$ is a function performed by the system; $P(t)$ is the performance measure of the function $F(t)$; $I(t)$ is the investment (e.g., dollars or other equivalent convenience of at-risk assets); and the time, t, is measured relative to the onset of initial investment in the project. The unit of *V(t)* is that of $P(t)$ divided by Investment (which could be quantified in terms of dollars or another meaningful measure an investment), since $F(t)$ is dimensionless.

The importance of functions was underscored in 1954 by Lawrence Miles when he conceived Value Analysis (and the subsequent development of the fields of Value Engineering and Systems Engineering) away from the parochial focus of simply providing system components. He based his functional analysis on the component parts of the product, the totality of which provided the desired functions. The purpose of functional analysis was to establish why an element exists so that alternative solutions could be generated (Green, 1996). Value Engineering is the activity which identifies and analyzes the function of products and services to achieve an overall effectiveness in providing system functionality. Systems Engineering is the activity which identifies and analyzes functions of products and services to specify the requirements that need to be built and sustained.

When applied to Gap Analysis, the metrics used for analyzing requirements are Value and Risk. Value is captured by the cost of Functions and their Performances, and Investment (measured in cost or investment). In common-sense fashion, Value is a measure of appreciation. It may be objective or subjective. Objective value relates to the idea that there is independence of assessments viewed from various perspectives—a consensus opinion of truth. Subjective value is based on what is expected (the sum of all corporal and abstract happenings from which you benefit and expect from a situation if you participate in a certain fashion). Value is simply the matter of minimizing cost or its time equivalency to develop a product. Value is the use that users expect (e.g., the functions and performance) for the investment they are willing to make. Further, Value is exemplified in the formulation of lifecycle costs and lifecycle time that express the transformation of company assets into profitably sold products that have a set of functions, performances, and quality. Each function is an activity that the product does with certain performance attributes. For each function, there can be several performance requirements. But there is never a function without a performance (Miles, 1954; Langford, 2006; 2007).

Worth

The notion of Worth extends the concept of value to include the intangibles of an indefinite quantity or other uncertainties. We define Worth as an indefinite quantification of something having a specified value. For example, "I have $20. Please give me $20 worth of gasoline." I have already determined that gasoline has sufficient value to warrant my purchasing it, and I have a limited budget of $20. I am willing to purchase more gasoline at a later time, when I either have more than $20, have more time to pump the gasoline, or have a current additional constraint removed. But, is it worth it to purchase from this vendor or another vendor at another location? Perhaps $20 purchases more gasoline at a different location from a different vendor. The $20 will purchase either Quantity X from Vendor A or Quantity Y from Vendor B, where Quantity Y > Quantity X. The difference in distance between Vendor A and Vendor B is 5 miles, so I must drive an additional 5 miles to transact and receive more gas than I could receive from Vendor A. This presumes I know with a high degree of certainty that Vendor B offers the gasoline appropriate for my use and provides similar performance at a price sufficiently lower than I can get from Vendor A so as to warrant travel to Vendor B. If my level of knowledge was lower about the price of Vendor B, then I must consider the worth issue in light of the uncertainty that Vendor B's price would be sufficiently less than Vendor A's price. In other words, is it worth the risk to drive farther and "shop" for gasoline? The loss may be quantifiable in the case in which Vendor B's price is known. Either the price is sufficiently lower to justify driving to Vendor B's location or it is not. If both the price and the distance are unknown, then there is less sufficiency and greater unknowns with which to deal. These unknowns can be incorporated into the Worth function as a determination of losses. If I do not locate a gasoline vendor before I "run out of gas," I will incur additional costs of purchasing a gas can and the cost of my time converted on a cash basis. Further, if I locate a gasoline vendor whose price is higher than Vendor A, then I have paid more than I could have paid.

By including the effects of high, sufficient, and low measures of quality, a decision based on Worth can be structured and evaluated in a methodical fashion. Obtaining sufficient information is typified by the trade-off between when one has paid too much or too little for either a given number of defects (1) as measured by a degradation or improvement in performance, or (2) which result in defects that are caused by certain levels of performance.

Worth as simply the ratio of the Value *V(t)* multiplied by the Quality *Q(t)* (Langford, 2006; 2007). Performance indicates how well a function is executed by the system. In this work, quality refers to the consistency of performance (or tolerance that signifies how good the performance is) in reference to the amount of pain or loss that results from the inconsistency as described by Taguchi (1990). In essence, functions result in capabilities; performances differentiate competing products; and quality affects the lifecycle cost of the product. For each function, there is at least one pair of requirements—performance and quality. The quality requirement indicates the variation and impact of the variation of the performance requirement of a function. A system function may thus have different values of performance, and the quality of a performance may have different values. The summation in Equation 1 is, thus, over all values of the functions, performance, and quality, for all time, and incorporating all uncertainties. Equation 2 indicates the Worth of system, as it references Value.

Equation 2. $$W(t) = V(t) * Q(t) = \frac{\sum F(t) * P(t) * Q(t)}{I(t)}$$

where $Q(t)$ is quality (the tolerance assigned to the performance measures), and the time, t, is measured relative to the onset of initial investment in the project. We refer to the delineation of a function in terms of its performance and the quality of the performance as the triadic decomposition of the function. If the unit of $Q(t)$ can be converted to the unit of $I(t)$ (Equation 1), then the unit of W(t) is that of $P(t)$, since $F(t)$ is dimensionless. $Q(t)$ can be thought of as a loss that is incurred.

Several schemes have been proposed to define and structure requirements, such as functions, performance, and tolerances/physical synthesis by Wymore (1993), hierarchical task analysis by Kruchten (2000), decomposition coordination method of multidisciplinary design optimization by Jianjiang, Zhong, Xiao, and Sun (2005), functional descriptions by Browning, Deyst, Eppinger and Whitney (2003) and Cantor (2003), and non-functional descriptions by Poort and Peter (2004). The functional triadic decomposition proposed in this work forms a basis for a management tool that provides a structure to control the project. Again, triadic decomposition prescribes that every function is imbued with the necessary and sufficient attributes of performance and quality. It forms a basis for a management tool that provides a structure to control the project.

Control centers on three functions (again, each with associated performance and quality): Regulate (monitor and adjust), govern (define limits, allocate resources, determine requirements, and report), and direct (lead, organize, and communicate).

Traditional functional analysis, supplemented with the triadic decomposition, is conjectured to result in a complete and comprehensive set of requirements. The resulting functional decomposition, together with commensurate system specifications and the mechanisms of action or activity (e.g., creation, destruction, modulation, translation, transduction), should form a basis upon which a system can be designed and built using the classical set of system development models—such as the spiral, “Vee,” and waterfall model.

The Value of a product is thus quantified according to Equation 1, and the Worth of a product is quantified according to Equation 2. From the manufacturer’s point-of-view, a “product’s worth” is one that has met some investment criteria for the desired set of functionality, performance, and quality requirements. From the purchaser’s (consumer’s) point-of-view, the expression in Equation 2 aids in the trade between the applicability of a purchased product (in terms of the item’s functionality, performance, and quality) and the total cost and time invested in the purchase and use of the product (Langford, 2006; 2007).

Value and Worth are calculated at the moment of the agreed exchange of product/services for a given amount or recompense. Worth reflects the uncertainties based on losses that are associated with the exchange. These exchanges (or interactions between elements) are quantifiable and may have a net impact on the Value and Worth of the system, or in the exchange between two or more systems through their respective elements, a system(s)-of-systems interaction. We are interested in the interactions that have consequences that are measurable in the lifecycle of the product or service. To incorporate this level of minimum interest, we introduce the concept of a Net Impact—defined as a consequence that exceeds a threshold that is determined to be of interest (Langford, 2006; 2007).

Worth Transfer Function

In control theory, a transfer function is a mathematical representation of the relation between the input and output of a system. A Worth transfer function (WTF) between two elements of a system is defined to be the exchange of Worth between the two elements. Worth is what is received (in terms of usefulness) for an investment. This exchange necessarily assumes some measure of risk. Given risk, a WTF can thus be either a manifestation of the state (or a change in the state of a system), or a tool to evaluate differences between the state of a system and the state of another system, or between the states of two systems in a system-of-systems. In essence, the WTF represents various impact(s) on the state(s) of a system. The WTF can be a nested hierarchy of WTFs, all related through functional decomposition. Depending on the worth ascribed to each of the WTFs, the state(s) of the system(s) may be impacted to varying degrees. The result is that a small number of WTFs may be equivalent to a large number of irreducible WTFs.

A system is a set of elements that are either dependent or independent but interacting pairwise—temporally or physically—to achieve a purpose. The elements form the boundary of the system. This definition takes into account both the permanent and episodic interactions among elements of a system or systems of a system-of-systems. It thus includes the lasting and occasional interactions, as well as emergent properties and behaviors, of a system. These interactions effect transfer of energy, materiel, data, information, and services. They can be cooperative or competitive in nature, and they can enhance or degrade the system Worth, which is defined below. The pairwise interaction transfers a measure of Worth from one element of a pair to the other element. We term the measure of the transferred worth the Worth Transfer Function (WTF).

Complexity

Complexity of a system is often characterized by the total quantity of units that make up the system. As described by Homer and Selman (2001) and Li and Vitanyi (2006), it is both the number of and interactions among the units that, in general, are used to imply and define complexity. The system complexity thus augments the management challenge because of the large number and various types of system elements and stakeholders. In this work, complexity is reflected by the number and significance of WTFs among the elements of a system or among the systems of a system-of-systems. Since an element of a system may also be a stakeholder of the system, an increase in the number of stakeholders increases the complexity. Managing complexity or managing stakeholders thus amounts to managing the WTFs. It must be noted that a stakeholder with a large WTF (i.e., a funding source with many requirements) may add no more complexity than does a large number of stakeholders with a few requirements.

Risk

Using the logic in Lowrance (1976), Lewis (2006) defines simple risk as a function of three variables: threat, vulnerability, and damage. By replacing damage with Worth, Langford and Huynh (2007) capture risk through threat, vulnerability, and Worth. An element e of a system is associated with a risk, R_e, defined by

Equation 3. $$R_e = X_e * U_e * W_e = X_e * (1 - a_e) * W_e$$

where, * indicates the convolution that expresses the overlap and blending of factors; and where, threat, X_e, is a set of harmful events that could impact the element; vulnerability, U_e, is the probability that element e is degraded or fails in some specific way if attacked; Worth, $W_e = V[1 - L_e]$, where L_e is the loss that results from a successful attack on element e; and susceptibility, a_e, is the likelihood that an asset will survive an attack. W_e is given by Equation 2. It may be a loss of productivity, casualties, loss of capital equipment, loss of time, or loss of dollars. Susceptibility is the complement of vulnerability. Equation 3 reflects these tentative affinities. One finds vulnerabilities in a worthy system from the threats to that system.

Since an element in a system (or network) may be connected to more than one element, the number of WTFs associated with the element is the degree of the element. Subscribing to Almannai and Lewis (2007), we obtain the system risk, R, as

Equation 4. $$R = \sum_{i=1}^{n+m} X_i * (1 - a_i) * g_i W_i$$

in which n denotes the number of elements; m denotes the number of links or WTFs, and g_i denotes the degree of connectedness (i.e., the number of connections) to the i^{th} element.

As a result of the WTF between two elements, e_1 and e_2, at the moment of their interaction, we have

Equation 5. $$\frac{W_{e_1}}{R_{e_1}} = \frac{W_{e_2}}{R_{e_2}}$$

It is the expression in Equation 4 that forms the basis for complexity management and acquisition.

Discussion

The approach extends the published and private works of Langford to identify and apply measurable objectives to characterizing and analyzing Gap Analysis. The two basic metrics are competitive *Worth* and a *Cost-to-risk* ratio. Both are displayable in an Enterprise Framework.

Gap Analysis fits into the overall scheme of acquisition by providing decision-makers with a structured and objective VoA from which to procure systems that satisfy defined needs. The desired results of Gap Analysis are to: (1) predict what we need for a postulated event, (2) compare what we need to what we have, (3) identify those items that need to be changed or added—along with the amount of investment in time and money required, and (4) enumerate the potential limitation of future capabilities. Recognizing there may be no means to maintain an optimal relation between the two limits—what we need and a potential limitation in capabilities—we assume the principles and practices of engineering are evolutionary and that the fundamental laws of physics prevail.

Further, we use generally accepted economics terminology, extended to encompass the notion that the price one pays for a product assumes and accounts for the loss realized to make the purchase (Taguchi, Chowdhury & Wu, 2005). That is, the purchase price of a product includes the cost of procurement—for example, the $1 purchase of a pen must be increased to $5 to include $0.50 of gasoline, plus amortized cost of maintenance, plus insurance, plus depreciation, and plus labor rate times travel time to drive to/from and make the purchase, etc. This notion states a willingness to spend (lose) $*x* to purchase a $1 item.

Following the accepted systems engineering process, product requirements are defined hierarchically, with each successive level offering greater detail via decomposition. However, unlike the different types of requirements that attach to various process models (e.g., functional and non-functional requirements), we define all processes and products by three measures—their functions, performances, and qualities (Langford, 2006; 2007). Relative to the Investment (Cost or its equivalent) to bring a product to operational capability, the product has determinable Worth. That Worth is expressed as a ratio of total value (i.e., operational capability or use as measured in terms of a unit of performance (e.g., work, throughput…) multiplied by Quality (effectively divided by the potential losses that could be incurred) and then divided by total lifecycle investment (i.e., expected cost for the use). As an example, if this ratio is less than 1, then the product has lower-than-expected worth.

Worth is related to both the vulnerabilities of the system and to the outputs of the system. The risks are a function of the threats and vulnerabilities, where threats are typed by magnitudes and frequencies, and vulnerabilities are determined by the likelihoods of success (DoD, 2006). The outputs of the system are related to the vulnerabilities through the price-demand elasticity curves (Lemarechal, 2001). The competition and the marketplace determine the threats; the operational strategy determines the vulnerabilities; and the triad of requirements determines the Worth (Langford, 2007).

To investigate the multivariate probability-density functions of the Risk Equation (Equation 3), a step-wise, two-variable analysis reveals both the boundary conditions and the relationships between Worth, Vulnerability, Threat, and Risk. Table 1 shows these boundary conditions. When any of the three variables (Worth, Vulnerability, or Threat) is zero, Risk is zero. And conversely, when Risk is zero, one or more of the three variables (Worth, Vulnerability, or Threat) is zero.

Table 1. Multivariate Boundary Conditions for Risk Equation

Worth = 0	Risk = 0
Worth = 0	Threat = ∞
Vulnerability = 0	Risk = 0
Threat = 0	Risk = 0
Risk = 0	Threat = 0
Risk = 0	Vulnerability = 0
Risk = 0	Worth = 0

A product that has Worth (quantified by the Worth Equation, Equation 2) from the developer's point-of-view is one that has met the investment criteria for the desired set of functionality, performance, and quality requirements. From the user's point-of-view, the Worth Function Equation emphasizes the trade that is made between the applicability of the purchased item (in terms of the item's functionality, performance, and quality) and the total cost and time invested to purchase, use and sustain the product. This total cost and time (accumulated over the product's lifecycle) is incurred not only during acquisition of the product, but also during the operation of the product and, finally, its disposal. This lifetime cost and time investment can also be viewed as a total loss to society (Taguichi, 1990), or as a specified loss as defined by a set of conditions.

Within the constraints of the boundary conditions indicated in Table 1, the relative ratios of Worth/Risk for an activity, a process, or a product or service may be displayed as probability density functions, and then summarized for display purposes as single data points. Figure 1 indicates two product lines—each drawn with designated points on curves depicting desirability, acceptability, and unacceptability. Product A (indicated on the upper right) has a higher market worth-to-risk ratio than Product B (lower left). The increasing worth-to-risk ratio moves generally upward. Product A can be compared to Product B on a one-to-one basis. Product parameters that indicate movement vertically upward reflect a decreasing threat but no change in vulnerability. Products that indicate movement horizontally to the left reflect decreasing vulnerability but no change in threat. Products that compete on price, such as the lower-priced Product B in Figure 1, have Event-space Strings (Langford, 2007) that are displaced upwards relative to their higher-priced competitors. Event-Space Strings are made up of sequences of causal events. These events are separated by probabilistic transitions rather than by either temporal or spatial (in the sense of being an adjacent event in a series) idealizations.

Consequently, Product B has a "Desired" position, which is higher than that of Product A's "Acceptable" position in the competitive Enterprise Framework. The higher position is indicative of the lower price (the lifetime cost to the consumer). If the lower price was offset by reduced functionality, performance, or quality, then the Worth would not increase. Product B is also located to the left of Product A, which indicates a reduction in vulnerability. This implies reduced risk and reduced threats. Therefore, as a competitive strategy, offering the lowest price with the highest utility is an efficacious strategy for competitors who are unable to match utility and pricing.

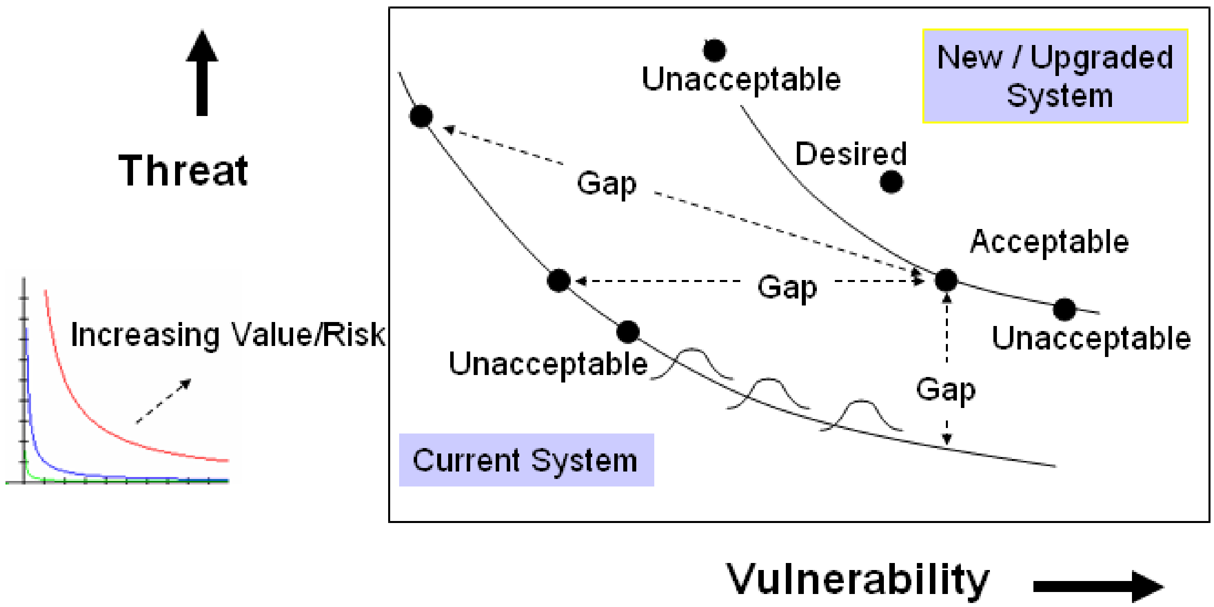

Figure 1. Enterprise Framework Illustrating the Worth-to-risk Assessment for Competing Products

The metrics for evaluating the Value-to-risk ratio or the Worth-to-risk ratio and their associated examples that describe contextual relationships are indicated in Table 2. These metrics are the rules which govern movement in the Enterprise Framework. Each rule corresponds to the impacts of business operations, competitive strategy, and the means or type of product offering. Event-space Strings are unique to a company's operations, strategy, and product offering. These rules describe the order of relative motions that have meaning appropriate to the context of a competitive space. Further, these rules are applicable to commercial products and services, the DoD battlespace, the procurement and acquisition landscapes, and the business environment considerations of business models and strategies.

In general, the Enterprise Framework is a visualization of decision-making processes in which the factors of value engineering, systems engineering, economics, acquisition, and operations research are involved. From such rules, the DoD Gap Analysis progresses in an orderly and logical fashion. Traditional statistical analysis, probability theory, and modeling are readily represented in proper context with conventional interpretation. As such, an error analysis results in confidence intervals for each point on the Event-space Strings. The scales of threat^{-1} and vulnerability^{-1} are determined by the probability of occurrence (0 to 1) multiplied by the frequency of occurrence (rate), and the odds of successfully inflicting loss (0 to 1), respectively. The vulnerability scale can be normalized in terms of dollars or numbers of items. Threats can be similarly normalized, as the situation warrants. Worth can be stated in either dollars or by numbers of items. Risk is a number between zero and one.

Of the possible rules (Table 2) for interpreting the Enterprise Framework, 31 have been identified; and thus far, 17 have been investigated. For example, Rule 1 implies a higher product utility (higher functionality, performance, and/or quality).

Table 2. Rules for Risk Equation in Enterprise Framework

Vulnerability ↓	Worth ↑	Risk -	Threat -	Rule 1
Vulnerability ↓	Threat ↑	Risk ↑	Worth ↑	Rule 2
Vulnerability ↓	Risk ↓	Threat -	Worth -	Rule 3
Vulnerability ↑	Risk ↑	Threat -	Vulnerability -	Rule 4
Vulnerability -	Threat ↓	Value -	Risk ↓	Rule 5
Vulnerability ↑	Worth ↓	Risk ↑	Threat -	Rule 6
Threat ↓	Risk ↓	Vul. -	Worth -	Rule 7
Threat ↓	Risk ↓	Unless vulnerability and/or worth ↑		Rule 8
Threat ↓	Risk ↓	or Worth ↓		Rule 8
Threat ↑	Risk ↑	Worth - and vulnerability -		Rule 9
Threat ↑	Risk ↑	Unless vulnerability and/or Worth ↓		Rule 10
Value ↓	Threat ↑	Risk -	Vulnerability -	Rule 11
Value ↓	Vul. ↑	Risk -	Threat -	Rule 12
Value ↓	Risk ↓	Threat -	Vulnerability -	Rule 13
Value ↑	Threat ↓	Risk -	Vulnerability -	Rule 14
Value ↑	Risk ↑	Risk -	Vulnerability -	Rule 15
Value ↓	Vul. ↑	Risk -	Threat ↑	Rule 16
Vulnerability ↓	Threat ↓	Worth ↑↑	Risk -	Rule 17

For a decrease in vulnerability (e.g., opening a new channel of distribution) due to a new competitive entrant in the marketplace (increase in threat), Rule 2 requires an increase in Worth commensurate with an increase in the Risk the enterprise is willing to accept. If the competitive landscape does not change and the enterprise's product remains the same, then opening up a new channel of distribution both decreases the product's vulnerability to competitive factors as well as reduces the enterprise risk with that product. Rule 4 indicates that an increase in vulnerability results in an equivalent increase in risk—if there are no changes in threat, and the product remains the same. Rule 5 indicates that a decrease in threat directly results in a decrease in risk if the enterprise's product and vulnerability are unchanged. Rule 6 implies that an increase in vulnerability decreases Worth (e.g., cost paid by a consumer increases due to a reduction in channel distribution) and increases the enterprise's risk if the threat landscape remains constant. Rule 7 indicates a reduction in the threat (e.g., competitors leave competitive space) results in commensurate reduction in risk, and the Worth and vulnerability stay the same. Rule 8 indicates a reduction in the threat (e.g., competitors leave competitive space) results in commensurate reduction in risk, unless either the product value or vulnerability increase—in which case, the overall risk would increase. Rule 9 indicates that as the threat increases, the risk increases, assuming the Worth and vulnerability remain constant. Rule 10 indicates that as the threat increases, the risk increases, unless either or both the value and vulnerability decrease. Rule 11 implies a greater investment in time and, therefore, a lower value and, hence, a higher risk. Rules 6, 12, and 16 each imply a lower product utility (insufficient functionality, performance, and/or quality). Rule 13 implies the product utility is worthless. Rule 14 implies a lower investment (time x money) and, therefore, a higher product Worth. Rule 15 implies the product has both higher utility and higher risk and is, therefore, worth more given that the threat and vulnerability remains unchanged. Rule 17 implies a disruptive technology or discontinuous innovation (Langford & Lim, 2007).

Following-up on this last rule that drives the display and interpretation of data in the Enterprise Framework, the discovery and analysis of potentially disruptive events and technologies (Rule 17) poses particularly incongruent issues for Gap Analysis. At issue is the degree of uncertainty that influences the choices and selection of alternatives in acquisition. The dangers of underestimating or not recognizing a disruptive technology or disruptive innovation result in a miscalculation of: (1) a sound operational vision, (2) the importance of planning and implementing an appropriate operational model, (3) the understanding of the relationships between current paradigms and a disruptive technology or innovation, and (4) the requisite acquisition strategy.

Finally, the graphical display of the competitive space (Enterprise Framework) found in Figure 1 portrays the results of Gap Analysis. From the view of the Enterprise Framework, the gaps reveal the needed capabilities, the prioritization of the capabilities, and the efficacy of the proposed alternatives. In the case of weapon systems, the Enterprise Framework is the geographical battlespace. It has physical structure, command structure, information structure, and engagement structure. Each structure is depicted in temporal- and event-driven layers. Truth is established through scenarios that illustrate capabilities that are enacted through these structures. Additionally, the Enterprise Framework illustrates opportunity shifts, allows evaluation of potential adversaries, and guides decision-makers' choices of what should be developed, indicates the system requirements that are satisfied by various strategies, illustrates potential target segmentations, and describes geographical arenas in the context of system capabilities.

General Formulation of Results

This work defines an Enterprise Framework in which to display the results of a Gap Analysis. For the purposes of this paper, an Enterprise Framework is a marriage of business parameters (reflecting operations and strategy) and product parameters (functions, performance, and qualities). The marriage is bonded through the structure of an expression of *Risk* (Equation 2).

In essence, the Enterprise Framework is an application framework that includes a multivariant view of a competitor's objectives, structure, and behavior. It is an adaptation of human activities into an abstraction that models the differences between these objectives, structures, and behaviors. Further, the framework is constrained by only two factors: geographical boundaries (for contextual structure) and a common event (to bring specificity to the nature of the competition).

Unlike the products of the domain analysis process, which processes imply a reference model for the semantics of the application domain, the Enterprise Framework described in this paper does not distinguish between such reference models, reference architectures, and the results of mapping a reference model (domain model) into an architecture style. Further, our Enterprise Framework is also not an analysis-only enterprise framework (Hafedh et al., 2002). It generally investigates the interfaces between a subject or action (e.g., issues, process or activity and other issues, processes or activities) and other subjects or actions.

However, in the case of Gap Analysis, our Framework has provided additional insight into its nature to examine its territory—the makeup of and changes in its surrounds, environs, relationships, and key drivers. There are different types of Gap Analysis "domains." Sometimes these domains are constrained by organizational demands, sometimes by personality issues, and sometimes by other circumstances. The internal structure of the Gap Analysis domains are arranged in particular patterns within an organization. Continuous functions (or patterns) are built and sustained by authoritative proclamation. Over time, such structures evolve to a mature environment that supports decision fitness and reliability in process planning. However, when the Gap Analysis territory is invoked, organized, structured, and enacted in response to stimuli, the outcomes of the work are predictably inconsistent and generally low in efficacy (Langford et al., 2006, December).

Additional questions arise when we formulate an overall strategy to analyze Gap Analysis: Do all organizations have Gap Analysis policies, strategy, procedures, processes, and rules? Are the enactments the same? How does Gap Analysis differ within and across organizations? What are the priority and process necessities that are observed? How and why does the position of Gap Analysis within an organization matter? Do the organization's position and priorities affect how Gap Analysis is performed, how it is interpreted, why it is done, how it is done, who does it, what is done, or when it is done? Are there general (or simple) rules that apply to all Gap Analyses?

These questions focus on the crux of the rules, roles (responsibilities), and mechanisms that determine how Gap Analysis is organized, and how host organizations change during the Gap Analysis process. It is one of the purposes of this research to move beyond the descriptive and correlative aspects of investigating Gap Analysis. While such an early mapping activity provides decision-makers the necessary framework to begin to understand and to identify areas for additional investigation, it must also identify the mechanisms responsible for the dynamics of Gap Analysis, and then determine how these mechanisms respond and contribute to the psychological cues, such as stimulation through signaling pathways.

The Enterprise Framework is a tool—a means to comprehend competitive business and operational models and product offerings, structured in forms that compare and definitively rate each. Additionally, market segmentations, niches, products, and upgrade strategies are readily apparent when coupled with a backward-looking series of event-space framings. An example of a generic Enterprise Framework is shown in Figure 1.

In the Framework, threat to the competitive offering is plotted versus its vulnerability. Risk is held constant, and Worth (Function, Performance, Quality divided by Investment) increases to the upper right. If a product is upgraded, the data point moves along the curve from the left to the right. The range of acceptability is indicated as Unacceptable (on the left) to Desirable (on the right). A Gap represents the space between data points. Moving from one curve to the next also indicates a Gap, but not an upgrade of an existing product. Rather, this Gap represents a form of Disruptive Technology in the competitive landscape. An increase in Worth is indicated as the points move "up" the curves to the top and to the left. A decrease in Worth is indicated as the points move "down" the curves to the bottom and to the right. The rules indicated in Table 2 illustrate the meanings and visualizations of Gaps. The scales of $Threat^{-1}$ and $Vulnerability^{-1}$ are relative scales for local normalization of the competitive parameters. In a more global summarization of Worth across multiple competitive domains, there are other issues, such as localized determination of value versus universal principles of value. For example, is it more valuable to go to a restaurant or to invest in a set of cooking utensils? Is it worth more to make such an investment? Some of the factors that need to be considered are the opportunities from "networking" at the restaurant versus the long-term investment in lowering the cost of eating. For the purpose of this paper, the authors relate only the localized competitive factors when comparing products.

Summary and Conclusions

Gap Analysis is fundamental to the US DoD acquisition system. The dismal results of time and cost overruns, ineffective use of constrained resources, and missed opportunities to make improvements without jeopardizing schedule and cost drive a critical evaluation of DoD acquisition (Rumsfeld, 2001). Since the cost and the success of acquisition are constrained by initial conditions, it is prudent to develop and apply tools that can help improve both the evaluation and the processes of acquisition. Gap Analysis, one of the key early-phase drivers of the acquisition process, has significant room for improvement.

This paper discusses the Systems Engineering Value Equation (Value Engineering) and the Worth Function in the context of the ratio of triadic decomposition of requirements based on functions, performance, and quality to the investment in time and cost. Investors and stakeholders have expectations about products they support. These expectations necessarily need to be met with a rigorous analysis of gaps. This notion has general adaptability and applicability to commercial and DoD acquisition. In the commercial sense, Gap Analysis tools can be used to better position products in the competitive market space. In the DoD sense, Gap Analysis tools provide a more effective use of constrained resources to support development activities.

The application of Gap Analysis to the general problem of satisfying requirements involves more than simply improving the methodology. Methodology that is encumbered with time-consuming steps and overburdened processes does not improve Gap Analysis. It is only through a streamlining of Gap Analysis that is efficacious, effective, and efficient that the forces and consequences of acquisition are better served. Thus, it is much more important and to the point to determine how to improve the outcomes of Gap Analysis (including the time to complete the Gap Analysis process) than to determine merely what can be improved with Gap Analysis. To that end, the actions of Gap Analysis should not be obstructed by insistence on unnecessary procedures and folderol. Straightforward application of the formulations laid out in this report result in the application of the sound value engineering and systems engineering processes that have generally become widely accepted as standard practices.

At least some future research on Gap Analysis should concentrate on the further expansion of the standards of earned value management as well as on the integration of new management practices to exploit fully the prowess of value engineering and systems engineering.

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