Systems of Systems Engineering in the Enterprise Context: A Unifying Framework for Dynamics

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Abstract *Systems of systems engineering (SoSE) takes place in the broader context of an enterprise, which we define very generally as a purposeful or industrious undertaking. Enterprises of greatest interest for SoSE are typically complex, multi-agent organizations or sets of organizations exhibiting the characteristics of Complex Adaptive Systems, including evolutionary and emergent behaviors at multiple scales. The most fundamental of enterprise purposes are manifest in enterprise operations, in which the enterprise interacts with the larger world external to itself, and this aspect of enterprise dynamics is modeled. SoSE is but one aspect of an enterprise's activities, and the whole set of enterprise activities is predominantly oriented towards accomplishing and supporting the enterprise's mission in operations. This paper proposes a unifying framework for understanding and modeling the organizational, technical, and system complexities of enterprise dynamics across a range of enterprise types as major acquisition program initiatives are undertaken to provide improved operational capabilities..*

Keywords: Systems of systems engineering, SoSE, complex adaptive systems, enterprise architecture, dynamics, operations, highly optimized tolerance, HOT, game theory.

1 Introduction

Many of the challenges in systems of systems engineering (SoSE) arise because SoSE happens in the context of a larger enterprise whose major focus is on operations, in which the enterprise seeks to accomplish its mission through interactions with the external world and acquire improved performance capabilities. To cite several U. S. government enterprise examples, the Departments of Defense and Homeland Security (DoD/DHS) have a key mission to defend against security threats under emergency conditions, the Federal Aviation Administration (FAA) primary enterprise mission is to facilitate safe and efficient air transportation, and the primary enterprise mission of the Internal Revenue Service (IRS) is to facilitate income tax payments by the U. S. public. Among these three agencies, their missions are quite different and their operations have very different characteristics – for example, processing of tax returns by IRS and Medicare health care claims by the Centers for Medicare & Medicaid Services (CMS) are quite repetitive, while those of DoD/DHS may be extremely situation-dependent and represent a very different enterprise "landscape". Key to improving SoSE is to better understand how enterprise dynamics influence and are influenced by SoSE and the capabilities acquisition process in general. For example, in the military realm, the National Research Council [1] says:

"...trying to implement network-centric operations capabilities as envisioned by the Department of Defense (DoD) is like trying to design and build a modern combat jet aircraft without resorting to the science of fluid dynamics."

To generalize, trying to conduct SoSE in the context of a complex, dynamic enterprise without a framework, if not a "science," for understanding enterprise dynamics has a significant likelihood of failure, of which there are numerous examples [2].

Previous attempts to characterize SoSE have not fully captured the enterprise dynamics context. For example, the United States Air Force Scientific Advisory Board [3] defines SoSE as:

"The process of planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system-of-systems capability that is greater than the sum of the capabilities of the constituent parts. This process emphasizes the process of discovering, developing, and implementing standards that promote interoperability among systems developed via different sponsorship, management, and primary acquisition processes."

While this definition certainly captures important hardware and software-oriented aspects of SoSE, and reference [3] does acknowledge that "interaction among the systems often includes human-to-human interactions," we posit that the dynamic behaviors of the enterprise acquiring new technologies to undertake a multi-agency mission require a somewhat different perspective. This perspective encompasses extensive organizational and human "system" interactions that often include systems and systems of systems (SoS) in a support mode. This is an important distinction that this paper treats as an enlargement of the scope of SoSE; an extension that might be viewed as a System-of-Systems-of-Systems problem.

To this end, this paper proposes a unifying framework that represents the fundamental characteristics of complex enterprises in a relatively simple but broadly applicable way. The purpose of the framework is to extend and apply SoSE to the acquisition process to insert technologies for performance improvement in dynamic, complex enterprises, employing effective governance, organizational and decision-making approaches. These approaches include incentive mechanisms and institutional restructuring, such as replacement of government functions with managed services provided by non-government entities. Different enterprise types may require different approaches to achieve improvements, and we suggest that modeling can be applied to help clarify which specific types of improvements and governance strategies are appropriate to different situations and enterprise types. The multiplicity of scales inherent in complex enterprises naturally leads to a hierarchy of modeling approaches for enterprise dynamics, as discussed in this paper. The unifying framework and modeling hierarchy presented in this paper constitute work-in–progress on a promising research direction to illuminate a very complex domain.

We also present exploratory research towards modeling the enterprise and its acquisition process at the highest level, using a hybrid approach based on highly optimized tolerance (HOT) and game theory (GT). Although this research is at an early stage, our long-term vision includes integration of enterprise dynamics modeling with enterprise architecture and engineering tools and methods to provide fully integrated support for SoSE in the context of a dynamic, multi-stakeholder enterprise [4].

2 A Unifying Framework

The unifying framework presented in this paper builds upon an enterprise view illustrated in Figure 1 [5]. In this view, there are three nested levels of enterprise control and interaction, which depend on the degree of dynamic stakeholder interaction. At the most interior level, dynamic stakeholder interactions are minimal, so the enterprise can "control and predict" dynamic behaviors. This is where traditional, highly-structured systems engineering is most effective. As dynamic interactions among stakeholders increase, the enterprise mode of operation changes to "influence and guess," and finally, as dynamic stakeholder interactions predominate, "intervene and observe" becomes the applicable mode. Most SoSE efforts in dynamic enterprises fall somewhere within these two outermost levels.

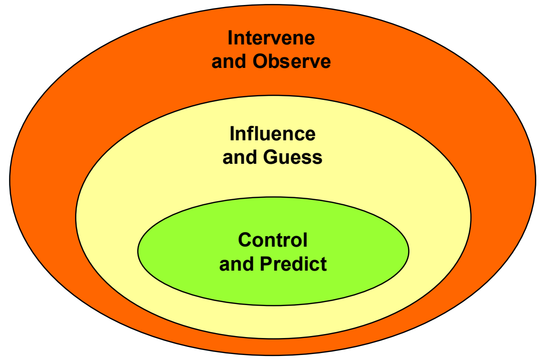


Figure 1. The Enterprise Context for SoSE [5].

Figure 2 diagrams the basic unifying framework of this paper, with enterprise operations indicated by the large inner oval and the external world with which the enterprise interacts shown as the large outer oval, which includes the public and legislative bodies as "customers" or "owners" as well as "users" and additional human and technical resources. "Operations" includes both those operations directly tied to the critical enterprise mission, as well as support operations that are tied to the enterprise mission in less direct ways. It is recognized that strategic decision making pertaining to the enterprise may be a complex, partly formal and partly informal, process involving multiple diverse stakeholders. This is represented by the smaller "Strategic Decision-Making Milieu" oval, which straddles the external world, since some decision making pertaining to the enterprise may actually come from the external world. Specific enterprise functions, including acquisition (which in turn includes SoSE), are represented in Figure 2 by the set of small overlapping ovals. The "enterprise" itself is not defined in the figure; this is deliberate, as the boundaries of the enterprise may vary, depending on perspective. In the examples presented in this paper, we take the perspective of regarding specific operational missions – the purposeful and industrious undertakings – such as those carried out by DoD/DHS as enterprises, but the unifying framework does not require this perspective. Individual components of the enterprise may be considered enterprises in themselves for some purposes, and this is recognized in Figure 2 with the label, "Acquisition Sub-Enterprise." Within each of these sub-enterprises, there is decision making and interaction with other elements of the larger enterprise, including the strategic decision making element.

A key for SoSE in this framework is how acquisition (including SoSE) relates to the larger perspective of the overall enterprise, which is predominantly concerned with its mission in enterprise operations. Figure 2 shows the relationship between acquisition and enterprise operations. Acquisition generates fielded capabilities, represented abstractly by the vector K, while the external world generates demand on the enterprise, represented abstractly by the vector Δ. The vectors K and Δ "meet" in enterprise operations. This interaction characterizes the enterprise in terms of its mission, and forms the basis for modeling enterprise dynamics at a strategic level. Note the importance of the time dimension in enterprise dynamics, as acquisition may take place well in advance of operations and over a much different time span. The time dimension is represented by the shading of the ovals in Figure 2. Feedback from operations influences strategic decision making as well as the acquisition process and the external world, as shown in Figure 2. This completes the framework, which (we claim) can be applied to a range of enterprise types. To the extent that sub-enterprises can operate with relatively structured and predictable feedback from operations and the decision-making milieu, these sub-enterprises may correspond to the "control and predict" oval of Figure 1. However, strong and unpredictable interaction are typical in SoSE, so that the acquisition sub-enterprise probably falls into the "influence and guess" or "intervene and observe" ovals of Figure 1.

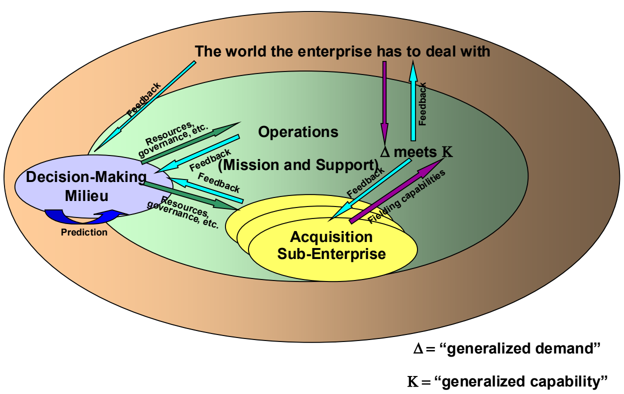


Figure 2. The Unifying Framework

3 A Modeling Hierarchy for Enterprise Dynamics

The proposed modeling hierarchy for enterprise dynamics has three levels, of which the first is strategic. This level of modeling includes the fundamental interactions between the enterprise and the external world. At this, the highest level, there may be long look-ahead to the future, perhaps spanning years or decades, although strategic decision making may be shorter term as well, if the decisions relate to the fundamental mission of the enterprise. The essential features of a general model at the first level of the modeling hierarchy include representation of planning as well as interactions between multiple enterprise decision makers and multiple decision makers in the external world, who may have different, and sometimes conflicting, goals. Various modeling methodologies may apply at this level, including highly optimized tolerance (HOT), control theory (CT), system dynamics (SD), agent-based modeling (ABM) and game theory (GT). In the example presented below of a general model applicable across a variety of enterprise types, a hybrid HOT and GT (HOT/GT) model is applied. HOT captures the planning aspect of strategic decision making [6], and GT captures the interactions between different decision making agents. Figure 3 shows the concept of how modeling at this level fits into the unifying framework; the red circle indicates that decision making is predominantly (although definitely not exclusively) done on the basis of interactions between K and Δ in enterprise operations. The black boxes and red arrows show interactions between decision makers, among those who influence the enterprise, among those who influence the external world, and between the enterprise and the external world. The black boxes also indicate some alternative modeling approaches.

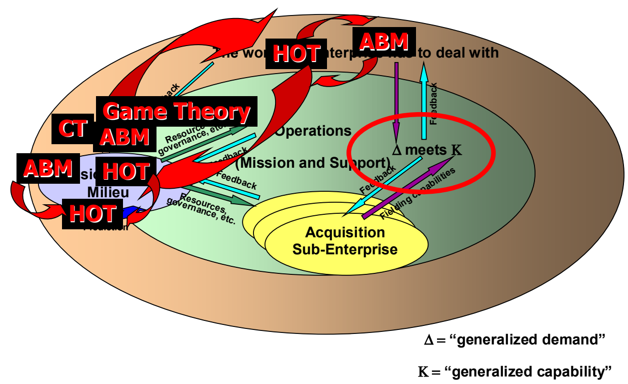


Figure 3. Modeling at the Highest Level of the Hierarchy

The second level in the modeling hierarchy addresses specific enterprise components at a more detailed level, such as the acquisition sub-enterprise, information systems, and other functions in support of the operations, with more emphasis on process and shorter-term adaptation, rather than on the strategic view and long-term planning. At this level, methodologies such as discrete-event simulation, SD and NK modeling may be appropriate, and there are examples in the literature of application of these methodologies to project management [7] as well as organizational and process adaptation in the transition to operations [8].

The third level in the modeling hierarchy addresses specific stakeholder interactions on short time scales in the context of operations. ABM is a suitable methodology at this level, and it is possible that methodologies like activity-based modeling and SD may apply as well. ABM models have been applied to stakeholder decision making interactions in such domains as air traffic management [9].

4 Modeling at the First (Highest) Level of the Hierarchy

This section describes a model for the dynamics of a range of enterprise types and their interactions with the external world using the hybrid HOT/GT approach. Modeling at the first level of the hierarchy is mainly for the purpose of illustrating and testing ideas, rather than for quantitative correspondence to actual enterprise behavior. Thus, we deliberately keep the modeling fairly simple and transparent. Ultimately, the intent is to model key interactions between a multiplicity of stakeholders for the enterprise and the external world, together with stochastic effects, but we begin with a very simple abstraction, a two-player deterministic game in which one player represents the enterprise and the other player represents the external world. Such a two-player game emphasizes fundamental interactions between the enterprise and the external environment, and we hope to expand the approach to reflect more of the unpredictable nature of enterprise dynamics as it influences the acquisition process and SoSE.

In the HOT approach, the system to be modeled is assumed to be optimized on average with respect to its structure and defined probability distributions for critical internal and external uncertainties, and implications regarding the system are drawn based on that assumption [10]. In modeling the enterprise at a strategic level, we need to take account of interactions between players (stakeholders, system users, etc.) with different objectives. In such a system, there is not necessarily an optimum state across all players; instead of optimization, an *equilibrium* approach is germane, and game theory can be used to identify one or more dynamic Nash game-theoretic equilibriums [11]. Equilibrium will not necessarily be achieved in real enterprises, but may represent a behavioral "attractor" that characterizes enterprise behavior at a high level. Each individual HOT stakeholder in the game is assumed to attempt optimization with respect to a cost function over some interval of time, taking into account the actions of other players, so the system-of-systems of interacting HOT models results in a non-zero-sum differential game.

In this simple two player differential game, we assume the costs per unit time (e.g. resources, opportunity costs, options, and risks) incurred by the enterprise and external environment are given respectively by:

$$L_{\mathrm{K}} = A \cdot (\Delta - \mathrm{K})^2 + C \cdot \Delta + B \cdot \dot{\mathrm{K}}^2 \qquad (1)$$

$$L_{\Delta} = D \cdot (\Delta - \mathrm{K})^2 - E \cdot \Delta + F \cdot \dot{\Delta}^2 \qquad (2)$$

In equations (1) and (2), A, C, B, D, E and F are assumed to be constants, while Δ and K are functions of time. Dots above these functions represent first derivatives with respect to time. The objective of the player representing the enterprise is to minimize its cost L_K integrated over a given time interval from 0 to T_F. Similarly, the objective of the player representing the external world is to minimize its cost L_Δ integrated over the same time interval. It is possible to extend this formulation of the game so that the enterprise and the external world have different look-ahead times, but that is beyond the scope of this paper. In both equations (1) and (2), the first term on the right-hand side represents the interaction between the enterprise and the environment. We will assume the constant A is positive, so that the enterprise finds it advantageous to produce operational capabilities K that tend to "match" the demand Δ imposed by the external world. The constant D, however, may be positive, zero, or negative based on the type of enterprise and external environment.

The second term on the right-hand side of equation (1) represents the operational objectives and/or burdens placed on the enterprise by the demand Δ by the external environment, even if the capacity of the enterprise is matched to the demand. Elements of these objectives and burdens may include capabilities provided, quantities delivered, services provided, and quality as well as regulatory and financial constraints placed on the enterprise. Thus, the constant C is assumed to be non-negative. Similarly, the second term on the right-hand side of equation (2) represents the benefit to the external world from the demand it imposes. In principle, the constant E could be positive or negative, but in typical cases we expect the external world to derive benefit from its operations, so E is positive.

Finally, the third terms in both equations (1) and (2) represent the difficulty of generating capability in the case of the enterprise and demand in the case of the external environment. The more difficult (and costly) it is to generate capability per unit time the larger is the constant B, and similarly for demand and the constant F.

Equations (1) and (2) can be generalized easily to make the terms they contain completely symmetric (allowing for unequal numerical values of the corresponding constants), which may be appropriate for modeling a wider range of enterprise types; for example, the U.S. DoD acting against a span of external environments, ranging from the past cold-war era Soviet Union through the current asymmetric warfare threat, but this generalization is beyond the scope of this paper.

From a traditional control-theory perspective, equation (1) can be solved for the first derivative of K to generate a non-linear equation of state for K with control L_K, if the function Δ is given. Similarly, equation (2) can be solved to generate a non-linear equation of state for external-world demand. In this perspective, the controls L_K and L_Δ correspond to the expenditures per unit time by the enterprise and the external world to attempt to achieve their objective of minimizing total cost over the time interval T_F. Both the enterprise and the external world face tradeoffs connected with making expenditures early to avoid costs later, and the system is further complicated by the fact that the enterprise and the external world interact – the consequences of what the enterprise does depends on what the external world does over the entire time interval, and vice versa. All these effects, which are important to understanding enterprise dynamics and SoSE at the highest level, are represented in a simple way by equations (1) and (2), which specify a non-zero-sum differential game.

Table 1. Necessary Conditions for Game-Theoretic Equilibrium [12]

$H_K = \lambda_K \cdot \dot{K} + L_K$	$H_\Delta = \lambda_\Delta \cdot \dot{\Delta} + L_\Delta$
$\dot{\lambda}_K = -\partial_K H_K$	$\dot{\lambda}_\Delta = -\partial_\Delta H_\Delta$
$\lambda_K(T_F) = 0$	$\lambda_\Delta(T_F) = 0$
$\partial_{\dot{K}} H_K = 0$	$\partial_{\dot{\Delta}} H_\Delta = 0$
$\partial^2{}_{\dot{K}\dot{K}} H_K \geq 0$	$\partial^2{}_{\dot{\Delta}\dot{\Delta}} H_\Delta \geq 0$

We solve the game for game-theoretic equilibriums in open-loop form with initial conditions specified as $K(0)=K_0$ and $\Delta(0)=\Delta_0$. An open-loop Nash solution specifies K and Δ as functions of time such that neither player has unilateral incentive to change. Although the perspective can be taken that the cost functions are the controls for equations (1) and (2), it is mathematically equivalent to consider the first derivative of the state variable in each equation to be the control variable. Then, the equations of state are the trivial equations,

$$\dot{K} = \dot{K} \tag{3}$$

$$\dot{\Delta} = \dot{\Delta} \tag{4}$$

The differential game specified by equations (1), (2), (3) and (4), plus initial conditions, can be solved using the Hamiltonian approach [12]. Table 1 shows necessary conditions for game theoretic equilibrium, with subscript K denoting the enterprise Hamiltonian and Lagrange multiplier, and subscript Δ denoting the external environment Hamiltonian and Lagrange multiplier. Partial derivatives are specified with subscripts as well.

Three types of open-loop game theoretic equilibrium solutions emerge, depending on the value of the constant parameter,

$$Q = \frac{D}{F} + \frac{A}{B} \tag{5}$$

When Q is greater than zero, solutions K and Δ are linear combinations of positive and negative exponential functions of time with time constant equal to the square root of Q, and second-degree polynomials in time. When Q equals zero, the solutions are fourth-degree polynomials in time. When Q is less than zero, solutions are linear combinations of sinusoidal functions and second-degree polynomials in time, with sinusoidal angular frequency given by:

$$\omega = \sqrt{-Q} \tag{6}$$

Figure 4 shows examples of solutions to the equations of Table 1. In each plot, the blue curve shows enterprise capability K as a function of time, the blue curve shows external environment demand Δ as function of time, and the green curve shows the difference, $\Delta - K$. The values of all constants in equations (1) and (2) except D, plus the time interval for planning, T_F are given in the figure caption. The value of D is varied across the different plots in Figure 4. For the purpose of distinguishing different enterprise/environment types, it is useful to sort different behavioral regimes according to the sign of the constant D. When D is positive, both the enterprise and the external environment favor matching enterprise capability to environmental demand, and they tend to co-adapt to reduce the difference in capability versus demand, in balance with their other objectives. "Cooperatively adaptive" defines the first behavioral enterprise/environment regime. The first plot in Figure 4, showing a solution with D=1, is an example of such a cooperatively adaptive enterprise and environment. The FAA enterprise and its environment of airspace system users probably corresponds to a cooperatively adaptive enterprise/environment system. When D=0, the environmental demand Δ is insensitive to enterprise capabilities, so its evolution in time is independent of K. However, the enterprise adapts to changes by the environment. This defines the second regime of enterprise/environment types: those with an "insensitive environment." The IRS enterprise and its environment probably corresponds roughly to the second regime. The third behavioral regime corresponds to D<0, and is characterized by an "oppositional" relationship between enterprise and environment, such as we would expect for the DoD/DHS enterprise and its environment of asymmetric threats. In this regime, the enterprise favors matching its capability with the demand of the external environment, but the external environment favors maximizing the *difference* between enterprise capability and environmental demand. The D=-1 plot in Figure 4 shows an example of equilibrium behavior in the oppositional regime. Both enterprise capabilities and environmental demand increase very rapidly, and their difference also increases with time, unlike the examples plotted for the first two regimes. As D is decreased beyond D=-1, the equilibrium rates of increase of both K and Δ rise until at approximately D=-1.02467, the rates of increase approach infinity. Thus, for the parameter values in the caption of Figure 4, the equilibrium solution to equations (1) and (2) has a singularity at approximately $D=D_{crit}=-1.02467$, corresponding to a "runaway capabilities/demand race" and no equilibrium solutions exist at lower values of D. (Of course, real enterprises and external environments will be constrained by factors not represented in equations (1) and (2), so the tendency towards infinite rates of increase might reasonably manifest as the most rapid rate of increase compatible with the additional constraints.)

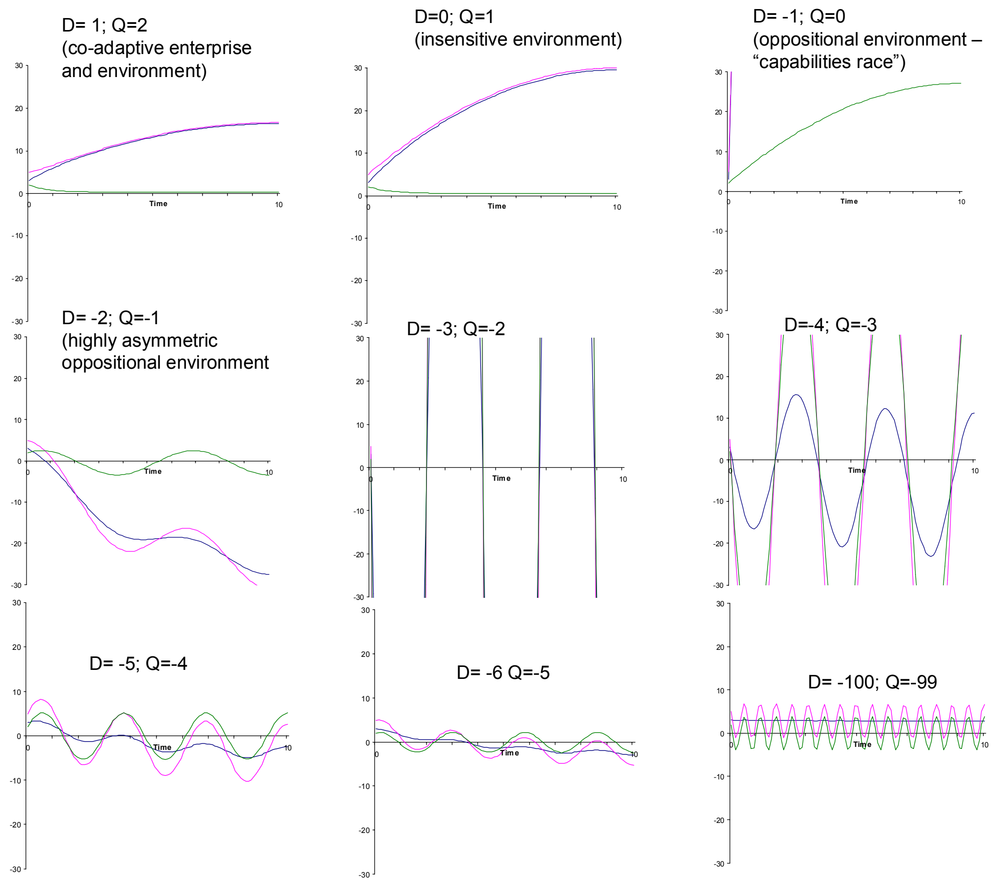


Figure 4. Example HOT/GT Co-evolutionary Solutions (A = C = B = E = F = 1; TF = 10; K(0)=3; Δ(0)=5). The blue curves correspond to enterprise capabilities (K), the red curves are demand from the external environment (Δ), and the green curves are Δ−K. For $D<D_{crit}$, the solutions are "local" game-theoretic saddle points, as described in the text.

Even though equilibrium solutions do not exist for $D<D_{crit}$, the necessary (but not sufficient) conditions in Table 1 can still be applied to generate "local" game-theoretic saddle solutions, and examples of these are depicted in Figure 4. A local game-theoretic saddle solution might be understood as behavior from which neither player has incentive to make small changes, or from which both players try to avoid a runaway capabilities/demand race. Thus, such saddle solutions may represent attractors for enterprise/environment behavior in some cases, especially those involving cost constraints that are not adequately represented in equations (1) and (2). Note the oscillatory behavior for these solutions and the large changes in oscillation magnitude as the value of D changes.

The interpretation of equilibrium solutions for $D>D_{crit}$ is straightforward: there is a marked tendency for the enterprise to increase its capabilities to "keep up" with rising and/or changing demands from the external environment. In the cases of cooperatively adaptive enterprise/environments (regime 1) and insensitive environments (regime 2), the enterprise is successful in reducing the difference between capability and demand. In the case of oppositional enterprise/environments (regime 3), the gap between capabilities and demand may grow with time, depending on parameter values, and there may be a tendency towards a runaway capabilities/demand race. Of course, these are very simplified caricatures of real enterprise and external environment behaviors, which are subject to many other forces and constraints.

Interpretation of local saddle solutions for $D<D_{crit}$ is more speculative and is a potential subject for further research. In these cases, capabilities and demand are better interpreted in qualitative rather than quantitative terms. The emergence of "natural frequencies" of oscillation invites investigation of whether such periodic phenomena can be observed in real enterprise/environment relationships, and comparison with other periodic behavioral theories, such as that of the Observe Orient Decision Action (OODA) loop [13,14].

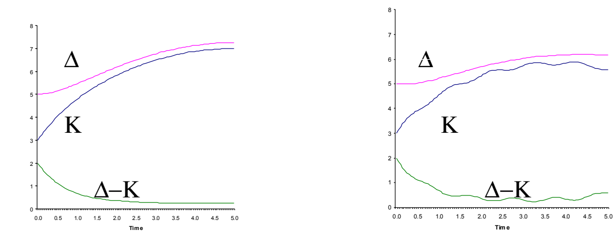
Additional terms can be added to equations (1) and (2) to represent "cyclical field effects." For example, equations (7) and (8) model a system in which the enterprise's cost function is affected by a sinusoidal driver that might represent, for example, a budget cycle.

$$L_{\mathrm{K}} = A\cdot(\Delta-\mathrm{K})^2 + C\cdot\Delta + B\cdot\dot{\mathrm{K}}^2 + g_{\mathrm{K}}\cdot\sin(\omega_{\mathrm{K}}t+\phi_{\mathrm{K}})\cdot\dot{\mathrm{K}} \tag{7}$$

$$L_{\Delta} = D\cdot(\Delta-\mathrm{K})^2 - E\cdot\Delta + F\cdot\dot{\Delta}^2 \tag{8}$$

In equation (7), g_K, ω_K, and ϕ_K are constants. The sinusoidal term is proportional to the first derivative of K to model a situation in which, at some times, it is relatively easy to increase K and at other times it is more difficult. Clearly, this is a very simple model of cyclical field effects, but we present results showing the effect on enterprise capabilities as well as on external world demand as illustrations. Figure 5 compares co-evolutionary growth of enterprise capabilities (K) and external-world demand (Δ) without the sinusoidal driver term (Figure 5a), and the effect on co-evolution when the sinusoidal driver is introduced in the enterprise cost function, as in equations (7) and (8) (Figure 5b). Note the periodic distortion in enterprise behavior (K) in 5b relative to 5a, but a different kind of distortion in external world behavior, resulting in reduced demand (Δ) in 5b relative to 5a. Further experimentation shows that the effect on enterprise and external world behavior may be strongly dependent on both the amplitude and phase of the sinusoidal driver. This suggests that programmatic timing can be a significant effect in acquisition programs; another possible area for further research is to investigate actual SoSE programs for evidence of such timing effects.

A possible interpretation of the constant D in equations (2) and (8) is that it represents a kind of "external boundary viscosity," i.e., a propensity for perturbations and disturbances to the enterprise to affect the external world and visa versa. As shown by the comparison of Figure 5, the effect of the enterprise on the external world may not appear as an obvious periodicity in demand. This suggests yet another avenue of research, to understand and model the nature of effects of enterprise perturbations and disturbances on the external environment, as well as the converse effects of changes to the environment on the enterprise. There is potential for mutually beneficial interaction between modeling and observation of real SoSE efforts.



a. b.

Figure 5. a. Base HOT/GT co-evolution of an enterprise and its external environment (A=B=C=D=E=F=1;T_F=5; K(0)=3, Δ(0)=5), b. HOT/GT co-evolution with a "cyclical field effect" applied to the enterprise cost function (g_K=1, ω_K=2π, ϕ_K=3π/2)

5 Conclusions

This paper presents a framework for understanding and modeling dynamic interactions and effects across the acquisition sub-enterprise including SoSE, the enterprise, and the external environment. The framework is general and potentially applies to many different enterprise types. The framework suggests a hierarchy of models corresponding to different scales of scope and time for the enterprise. We present a few examples of government enterprises and draw some preliminary connections between models at the highest level of the modeling hierarchy and the government enterprises.

The research results in this paper are at an exploratory stage, but suggest potentially interesting avenues for future research, including "natural frequencies" in enterprise/environment interactions, "internal viscosities" in adapting to change and "external boundary viscosities" between the enterprise and its environment and the associated propagation of effects (including distortion) across the enterprise/environment boundary. We suggest that the payoff for modeling of enterprise dynamics is very high and worthy of further exploration and development, and provides a useful complement to case studies. This conclusion is fully supported by the National Research Council Report on *Network Science* [1]. Ultimately, our vision includes integration of enterprise dynamics modeling with enterprise architecture and engineering tools as well as planning and decision support methods to provide fully integrated support for this expanded perspective on SoSE to a dynamic, multi-stakeholder environment with explicit definition of the human, organizational and governance "systems" – an aggressive multi-disciplinary System of Systems of Systems research progam will be needed to realize this vision.

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