Systems Thinking-Enabled Real Options Reasoning for Complex Socio-Technical Systems Programs

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ABSTRACT

Large scale development programs, policy creation initiatives, and manufacturing enterprises have two characteristics in common: *uncertainty* and *risk*. While program managers tend to have several tools to mitigate and manage risks, uncertainty is a whole different matter in that uncertainty can potentially be exploited if flexibility is introduced in the right technical and programmatic dimensions. For example, for large scale systems development, the key dimensions in which flexibility can be introduced are the technical architecture of the system, the program plan, and the design of the performing organization. However, introducing such flexibility into any one dimension does not mean that it can automatically be exploited. This is where systems thinking plays an important role. What are the implications of introducing flexibility into a particular dimension? What else needs to be in place to exploit this flexibility? For example, by introducing flexibility into the technical architecture, we give ourselves the opportunity to change the architecture, but change is only feasible if the program has sufficient flexibility in schedule and cost to accommodate the technical change. Similarly, the program can have this flexibility only if the performing organization has sufficient flexibility in how it is structured and how it can resource a program. Real options offer a viable approach to introducing flexibility into these key dimensions for a fraction of the investment that otherwise would have to be made up front. With real options, the performing organization retains the right but not the obligation to exercise the option. This paper presents real options reasoning (ROR) informed by systems thinking as a cost-effective approach to building flexibility into systems/products, programs, and organizations. It offers examples from three very different domains and problems of different scales to illustrate the universality of the approach. It emphasizes the importance of systems thinking when specifying real options to ensure that the real option can be exercised in the real world. It argues that the implications of introducing flexibility into a particular dimension need to be understood from the perspective of the constraints that such flexibility imposes on other dimensions.

INTRODUCTION

Lessons learned from large-scale programs suggest that most cost over-runs and performance problems are potentially avoidable if sufficient flexibility is built into the technical architecture of the system, and the implications of such flexibility are reflected in the program plan and the structure of the performing organization. Such flexibility enables an organization to make investment and deployment decisions in stages rather than all up front. Such flexibility can also enable changing the scale of the project, the system configuration, the feature set, and the organization configuration. Equally important, organizational flexibility provides for the abandonment decision which, in certain situations, may be the only viable course of action.

ROR is potentially an effective management instrument that can offer program managers and other decision makers substantial flexibility to exploit opportunities as well as limit the consequences of failure. ROR provides decision makers the right without the obligation, to take an action at a pre-determined cost (exercise price) for a pre-determined period of time (time to expiration). ROR enables the decision maker to defer, expand, contract, or abandon a project over time. Unlike financial options, which have a definite period (e.g., months) within which to exercise the option, real options can have an extraordinarily long exercise period (e.g., years). A key question that needs to be answered with respect to real options is how to value the impact of an option, given that not all value can be monetized. In this regard, it is worth noting that the value of a real option includes both cost savings in operation and maintenance as well as the increase in operational value.

Upon applying a systems thinking perspective, it becomes apparent that if flexibility is introduced into a system's architecture to allow for last minute technology changes, then this feature can only be exploited if the program has sufficient flexibility in schedule and cost (Madni, 2011). Furthermore, if technical and programmatic flexibility is built-in, then these characteristics can be exploited only if the performing organization has the requisite structural and resource flexibility (Figure 1).

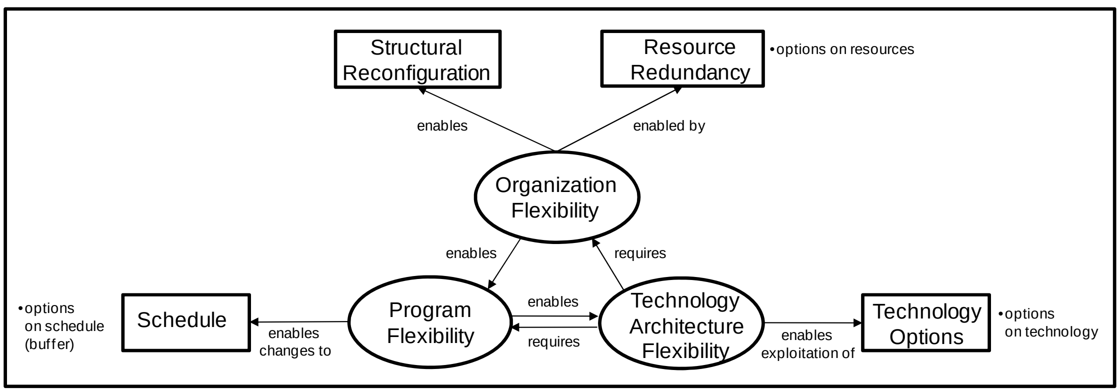

Figure 1. A Systems Thinking View of Real Options

From the foregoing, it becomes apparent that ROR offers a useful framework for evaluating technology investment decisions in the face of uncertainty. *Deferral option reasoning* offers the benefits of waiting for new information to arrive, while *growth option reasoning* stresses the value associated with early investments that enable expansion into the future by garnering mindshare and, ultimately, market share. The problem today is determining which course of action to pursue in what circumstance. Early adoption can give a leg up, but then again it runs the risk of a superior technology becoming available in time to render the original choice obsolete. Delayed adoption may enable exploitation of a superior technology but incurs the risk of losing out on an opportunity. The technology adoption decision involves tradeoffs between the benefits of early adoption of available technology and expectations about the characteristics and timing of the next generation of technology. Often incremental adoption of technology becomes a viable approach to replace or expand existing systems in a time of ongoing technological change.

LARGE-SCALE SYSTEM SCENARIOS

Program managers and other decision makers engaged in large-scale programs tend to be comfortable making decisions under risk because they view risk as a statistical expectation value amenable to probabilistic risk analysis. Unfortunately, this approach quite frequently leads to suboptimal results and, occasionally, failure when interpersonal factors and relationships, such as agency, intentionality, consent, and equity, are not factored into the analysis (Hansson, 2003). More difficult yet are those strategic decisions that have to be made in the face of uncertainty, because these decisions are based on available contextual information without the benefit of "legacy" heuristics. For example, when faced with uncertainty, managers might tend to delay committing to additional R&D, or might invest in incremental R&D to secure an option for a future opportunity. These behaviors, which are pervasive regardless of the problem domain, are discussed in the following paragraphs.

Consider a *pharmaceutical company managing a portfolio of technologies* in various stages of development. The company is faced with having to make decisions about research investments, acquisitions, in-licensing of early stage technologies, managing the FDA process, and making capital investments to manufacture the product in the face of uncertainty and risk. Even deciding which molecule from among hundreds of potential molecules on which to focus development is a gamble. Now consider the *complex military system required to manage air operations* in war time. This system coordinates multiple organizations/units to accomplish required functions (e.g., continuous context monitoring, target selection, strike path generation, rapid execution of plans and decisions) in the face of temporal and location uncertainty. Assessment of results is relatively immediate and offers evidence of success or failure. Now envision the *government of a country attempting to implement an environmental policy* to deal with pollution and sustainability issues. Not only must it interact with other countries on a global scale, it must also coordinate policies within its own borders, design incentives to change behavior, develop programs to educate its citizenry, make investment decisions about green technologies, and synchronize the efforts of multiple layers of government and non-governmental organizations to achieve desired policy goals.

The foregoing scenarios represent three very different types of large-scale, complex systems problems, each with its unique set of strategic decisions that, handled correctly, can produce distinct opportunities to exploit. For the pharmaceutical company, how decisions are made has important implications for product design and the company's ability to control the right to make future investments in promising technologies—in short, its potential competitiveness. For the military command and control system, being able to rely on various constituent systems and proven processes is critical to the ability to make effective decisions in the face of uncertainty. For example, for such systems, decisions about incremental technology adoption to replace/expand existing systems in times of uncertainty become critical. For governmental policy organizations, the greatest challenge is producing desired outcomes over a period of years based on the decisions it makes in the present. This problem is exacerbated by the fact that politics tend to enter into decisions at every level.

As different as these scenarios are, they all face a common challenge: making strategic decisions in the face of uncertainty – decisions that can be expected to have a major impact on the system as a whole. The question that needs to be answered is this: do methods exist that can be applied to the technology adoption decision in any complex system dealing with uncertainty, such that opportunity identification, technology selection based on technology maturity and other characteristics, and technology adoption timing can be effectively orchestrated and managed.

REAL OPTIONS REASONING (ROR) AND SYSTEMS THINKING

Real options reasoning (ROR) is potentially an effective tool for increasing technological, programmatic and organizational flexibility in large-scale systems development. It enables program managers and other decision makers to better exploit opportunities when they occur while limiting the consequences of potential failure (Madni, 2011). ROR creates the right but not the obligation to pursue a future opportunity (McGrath, 1997). More specifically, when faced with a strategic decision, the decision maker has the option to defer, to stage or sequence the investment or commitment, to alter the scale of commitment, to change any of the inputs or outputs, or to abandon the option (Trigeorgis, 1993). In other words, real options reasoning (ROR) provides decision makers with a new way to frame decisions and with a new perspective on how to deal with uncertainty because it accommodates flexibility. ROR presumes that decision points have “information asymmetries, path-dependent accumulation processes, and uncertainty” (Miller, 1998; McGrath and Nerkar, 2004). It also assumes an organizational structure that permits efficient abandonment of paths that turn out to be infeasible. .

In essence, ROR is a flexible strategy that offers a unique way to structure decision making (Janney and Dess, 2004) in complex organizations with uncertain resource allocation timelines and performance outcomes (Chatterjee, Lubatkin, and Schulze, 1999). In an environment characterized by uncertainty, the decision maker cannot know the potential result in advance of making the decision. In fact, decision makers operating in complex system environments typically make a series of decisions, all of which are executed under conditions of uncertainty. An option, which forms the basis for a decision, only has value to the extent that there is uncertainty associated with it. Therefore, complex system decision making tends to produce higher impact outcomes with more value associated with it (Kogut and Kulatilaka, 1994a; Kogut and Kulatilaka, 1994b). ROR favors exploration, along with a sense-and-respond approach that can overcome the inherent behavioral biases that often affect managerial decisions (Miller and Arikan, 2004).

Decision making in complex systems under high degrees of risk and uncertainty does not lend itself to traditional management practices such as optimizing for efficiency. While it may be feasible to optimize a part of an organization, there can be unintended consequences at the system level due to interdependencies among the various parts of the organization (Sargut and McGrath, 2010). To the extent that interdependencies can be reduced and time delays can be built into the system, decision makers can potentially have more time to reflect on the ramifications of their decisions. Specifically, interdependencies often produce compound options where the value of the original option is only realized after committing to next decision stage. This is quite different from the net present value approach to options in which independence is assumed and each project is accretive (McGrath and Nerkar, 2004). Triangulation, a technique used to manage complexity and interdependence, is compatible with ROR. It consists of gathering diverse information from multiple sources to inform the decision. If the different perspectives lead to the same conclusion, the decision maker has greater confidence in the final decision (Sargut and McGrath, 2010).

What seems critical to the adoption of a ROR approach for non-financial problems in an organization is that: 1) the option value cannot be made more attractive by the decision maker; and 2) the market value for the option must be readily observable (Adner and Levinthal, 2004b). What poses a problem in the adoption of ROR under conditions of uncertainty is the "impossibility of proving failure." In other words, the decision maker can only prove that the decision will be successful under pre-defined conditions. The decision maker cannot prove that it will succeed or fail under other market conditions (Popper, 1959). The impact of organizational factors on ROR increases when decisions regarding strategic opportunities are considered because the uncertainty associated with these options is largely endogenous to the organization and the set of possible changes is immense (Adner and Levinthal, 2004b).

This is where systems thinking can play an important role. Systems thinking is a way of thinking that is well-suited to addressing complex, uncertain real world problems. It is a framework that focuses on inter-relationships and dependencies among entities, not the entities themselves. It is an aid in circumscribing the problem without leaving out important inter-relationships and dependencies, and for addressing uncertainties and opportunities. Systems thinking is complementary and synergistic with ROR. While ROR focuses on exploiting uncertainty in system development and program management, systems thinking helps ensure that the problem is being fully addressed, and loops that should be included are not inadvertently left out. In other words, systems thinking ensures that all the "loops are closed" with respect to impacted variables, thereby ensuring that real options are conceptualized and introduced correctly in the system architecture and program plan.

ROR IN SYSTEMS ENGINEERING AND PROGRAM MANAGEMENT

The management of large-scale systems programs invariably face uncertainties, which stem primarily from changes in the operational environment. Technology Readiness Levels (TRLs) are related to program risk. TRLs relate a numeric integer value assigned to technology maturity. In the DoD, a TRL of 6 or higher indicates that the risk of inserting that technology into a new system is relatively low. In general, higher TRLs imply lower risks. TRLs are often mapped to a qualitative scale, indicating the likelihood of achieving an impact. A TRL of 1 or 2 would map onto "unlikely" on the qualitative scale while TRL 7 or 8 would imply "quite likely." While certainly not an exact mapping, TRLs provide an established mechanism to improve likelihood estimates. In this regard, it is important to identify the points of leverage within the program plan, where real options can be employed to exploit opportunities made possible by technology breakthroughs while limiting the downside by abandoning unproductive technology options.

ROR in systems engineering and program management is in its embryonic stages. The key challenges are identifying where to embed real options in the system and/or the program plan to derive maximum benefit. To identify the most effective insertion points, systems engineers require knowledge about the physical and non-physical aspects of the system, insights into sources of change, and the ability to examine the dynamic behavior of the system.

Wang and de Neufville (2005), Wang (2005), and de Neufville (2003) built on the concept and theory of real options to distinguish between managerial flexibility (real options "on" projects) that is emergent or coincidental in the development and operation of a system, and flexibility that has to be anticipated, designed, and engineered into systems (real options "in" projects). Case studies of real options "in" projects include those by de Weck at al (2003), who proposed alternative programmatic and technical designs for the Iridium and Globalstar systems so that flexibility was created through staged development; Markish and Wilcox (2003), who explored the coupling between technical design and programmatic decisions as they provide flexibility in the deployment of a new family of aircraft; and Zhao and Tseng (2003), who investigated the flexible design of a parking garage with enhanced foundation and columns, that can be added on to satisfy an increase in local parking demand. Despite these examples, flexibility design and real options "in" systems are still in the nascent stages. The case studies, while appealing, did not impact how systems are designed and developed. Some of the main reasons, according to Kalligeros (2006), were that the examples were over-simplified and appeared contrived, the performing organization's incentive structure was not conducive to the creation of flexible systems, and there was no technical guidance on how to model design and development decisions as real options. Consequently, both the concept and practice appeared restrictive, counter-intuitive and difficult to understand by practitioners.

An important advance came about when Steward Myers extended the concept of an option to situations where no formal contract is written. Instead, the option holder has the right without the obligation to instigate a specific action within a time frame in the future (Myers and Brealey, 2000; Dixit and Pindyk, 1994). This was a conceptual breakthrough in that the options methodology was used to value non-financial assets whose value depended solely on an observable financial entity and the asset owner's actions.

Initially, option valuation methodologies tended to be slow to penetrate management practice because these methodologies were tied to a set of assumptions that managers viewed as too formal, unrealistic, and incomprehensible. Copeland and Antikarov (2001) were among the first to introduce rigorous options analysis to project valuation and practice. Their work built on academic research in various types of real options most frequently encountered in the management of engineering systems (e.g., design deferral option, abandonment option, growth option, switching operational modes and scales).

Kalligeros (2006) proposed an overall approach that combined two complementary approaches: platform-based methods for standardization among platform variants with different functional requirements; and a real options methodology that maps design and development decisions to structures of real options with a simulation-based algorithm for valuation. This methodology overcomes some of the major impediments in adopting the financial options methodology within systems development.

Based on a graphical language to communicate and map engineering decisions to structures and equations characterizing real options, this approach employs simulation-based valuation and invokes equilibrium, rather than non-arbitrage arguments for options pricing. This methodology sacrifices economics rigor and some accuracy in valuation by making an important distinction between *correct valuation* and *optimal design decision*, the latter being its objective. This insight makes this methodology appealing and useful.

ROR IN MANAGEMENT AND ORGANIZATION DESIGN

From a strategy perspective, ROR is grounded in three broad research areas: 1) the resource-based view of the organization; 2) basic organizational theory, and 3) complex adaptive systems (Kogut and Kulatilaka, 2001). Since the dawn of the twenty-first century, the view of an organization has shifted from a mechanistic or management science perspective to a more holistic, systems perspective that defines an organization as a socio-cultural unit with multiple interrelationships that create complexity (Gharajedaghi, 2006). Those who have focused on systems methodologies have viewed the organization as a complex, socio-cultural system (Ackoff, 1999; Senge, 1990; Senge, 2007) that is able to self-organize to adapt to change and to structure itself appropriately under new circumstances to achieve the outcomes sought (Boland, Jelinek, and Romme, 2006). An organization with these qualities is deemed to be resilient. A resilient organization is designed to deal with uncertainty by avoiding the tendency to create policies that prevent negative outcomes and, instead, create policies that enable the organization to proactively understand potential threats (Sargut and McGrath, 2010; Madni and Jackson, 2009)

Resilience, in particular, and flexibility, in general, are important organizational characteristics for dealing with uncertainty. One important way to assess an organization's degree of flexibility is to examine how it is structured to enable an abandonment decision. Abandonment is an important concept because ROR decisions are typically made and committed to at very early stages so that any potential future option can be exploited at a later stage. In this respect, ROR is not about leveraging existing assets but rather about creating future paths or opportunities (Adner and Levinthal, 2004a). The flexibility to entertain abandonment of an option requires a counterbalance of structure in the organization in the form of policies that specify the acceptable possible paths when the first option commitment is made. Because it is usually impossible to determine ex ante the exact nature of the window of opportunity for executing or abandoning an option, a great deal of uncertainty is created. Furthermore, holding open options indefinitely in an effort to gather more information and reduce uncertainty is a drain on an organization's human and financial resources when many forces endogenous to the organization work against the abandonment of an option even when it makes complete sense. Examples of these forces are psychological deterrents such as sunk costs, escalating commitments, over confidence, and the desire to avoid failure (McGrath, Ferrier, and Mendelow, 2004).

The resource-based view of the firm finds that capabilities are important resources of an organization because they essentially represent an investment in future opportunities (Kogut and Kulatilaka, 1994b). Furthermore, a core competence is considered to be a scarce factor with inherent complex options on future opportunities (Barney, 1986). In other words, the value of a core competence is a function of its future and uncertain application and is, therefore, exogenous to the organization.

The literature on systems thinking and organizational performance is quite rich with respect to themes and concepts, but the empirical research, what little there is, has not come to an agreement on the relationship between systems thinking and organizational performance (Ellis, Gregory, Mears-Young, and Ragsdell, 1995). In large part, this is due to the fact that researchers have defined systems thinking and organization performance in different ways, making it difficult to compare the results of studies in these two areas. Furthermore, most systems thinking research has tended to focus on the leadership perspective.

ROR has been found to be useful for decisions that involve such things as the termination of joint venture agreements (Kogut, 1991), the management of multinational organizations in multiple locations (Kogut and Kulatilaka, 1994a), and venture capital investments (Hurry, Miller, and Bowman, 1992). The common thread among these three types of decisions is a staged process where an initial decision is made to invest time, money, and other resources to gather additional information that may lead to a next-stage investment.

From a management and organization perspective, ROR is used in a number of important ways that serve to modify the traditional two-stage commitment process to reflect environmental influences. The first type involves immediate entry into the market by means of an option that commits the organization quickly in a small way to "purchase" the right to fully commit at some time in the future (Janney and Dess, 2004). This approach is valuable where a firm is attempting to create a standard in the industry or secure market niches before competition enters and set up barriers that will make the process more difficult for competitors. The firm gains the opportunity to better understand industry processes and potential customer needs. The second type of ROR strategy involves executing a *full commitment* at the outset with the option of reversing that decision at some point in the future. This approach is more expensive and carries more risk but is often necessary in situations where a full complement of resources is required even to secure initial information; in other words, there is no viable way to make a limited decision. The third type of option strategy, *all in*, is a modification of the first strategy. In this version, the organization is faced with the need to enter the market in a big way rather than a step at a time thus making a major commitment of resources that is essentially irreversible. This strategy is often employed as a defense in a situation where the organization is a late mover in the market and the cost to exit is enormous. The final strategy involves a *delayed exit*, which permits the organization to buy time before executing an irreversible decision to abandon a previous option decision. In large organizations, these four strategies are often combined or modified to enable a portfolio approach where multiple projects or products are in play.

When an organization's model employs an ROR approach, one of the key variables that is tested to account for uncertainty is the degree of statistical variance (worst outcome to best outcome) for potential effect (Dixit and Pindyk, 1995). The variance often dictates which projects go forward and which get rejected as well as which option strategy is ultimately employed. If the typical variance between worst and best outcomes is extremely high, as in the case of an unprecedented outcome, for example, the organization may decide to fund one stage that has a more manageable level of risk associated with it, which gives it more time to decide on whether a second-stage commitment is warranted.

CONCLUSIONS AND OPPORTUNITIES FOR FUTURE RESEARCH

This paper has presented the use of real options informed by systems thinking as a means to cost-effectively introduce flexibility in large-scale initiatives with a view to exploiting uncertainty in the initiative. Specifically, the use of real options reasoning to create architectural flexibility in systems and schedule flexibility on programs is presented. Illustrative examples from three very different domains are discussed to illuminate the commonalities between the exemplar scenarios and the use of ROR to capitalize on uncertainty. ROR is a rich and fertile area of research. Going forward, there are several high payoff research areas that need to be investigated. These include: explaining how managers make choices in light of their options, and how they acquire and discern the options available to them at any point in time and over time; developing better measures of value and variability when entering a new technology area or market; and determining how to value options for non-financial decisions (e.g., business commitments). Research is also needed relative to the erosion of option value and expiration of options. Specifically, better understanding is needed about the behavior of decision makers. For example, do decision makers let options expire as uncertainty reduces over time? Real options reasoning is an exciting area of research that is still in its early stages. Advances made in this area can be expected to have significant impact on strategic decision making in the face of uncertainty in a variety of domains.

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