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Managing Uncertainty in Socio-Technical Enterprises using a Real Options Framework

Tsoline Mikaelian, Donna H. Rhodes, Deborah J. Nightingale, Daniel E. Hastings
Massachusetts Institute of Technology
77 Massachusetts Ave., Cambridge, MA 02139
tsoline@mit.edu, rhodes@mit.edu, dnight@mit.edu, hastings@mit.edu

Abstract

Real options analysis has traditionally been applied to the valuation of capital investment decisions. More recently, real options have been applied to the valuation of flexibility in system design decisions. However, different applications of real options are often considered in isolation. This paper introduces an integrated real options framework that supports holistic decision making under uncertainty for enterprises. This is accomplished by first introducing a new characterization of a real option as a tuple consisting of a mechanism and type, which disambiguates among 1) patterns of mechanisms that enable flexibility and 2) the types of flexibility in an enterprise. A new classification of mechanisms and types of options based on "where" they are embedded within the enterprise architecture is then devised, in order to enable a more comprehensive consideration of real options opportunities. The enterprise architecture in this context is described in terms of eight enterprise views and their dependencies. Modeling of the enterprise dependencies using a coupled dependency structure matrix (C-DSM) may be leveraged to propagate the impact of uncertainties and identify feasible types and mechanisms of real options. Examples are presented from a mini air vehicle (MAV) project, where challenging decisions span technical and social dimensions.

Introduction

Many complex systems are subject to uncertainties that may lead to suboptimal performance or even catastrophic failure if unmanaged. Designing systems that are robust in the face of uncertainties has been a top priority. Much research has been devoted to improving system design methods and developing tools for uncertainty management in complex systems design and operation. The development of better system designs is necessary, but not sufficient for success. For example, catastrophic failures such as the Space Shuttle Columbia accident have uncovered flaws in the decision making processes at NASA (Columbia Accident Investigation Board 2003). Such catastrophic events have suggested that failures may be rooted at the organizational level and not necessarily at the engineering design level. It is therefore important to recognize that complex systems are developed and operated by complex enterprises (Allen et al. 2004) that are in turn subject to uncertainties. This motivates research into decision making processes and uncertainty management practices within enterprises.

The goal of decision making under uncertainty is to make decisions that manage the risks that arise from uncertainty while simultaneously enabling the pursuit of opportunities. Uncertainties facing complex enterprises and systems may be managed through flexibility, which is defined in the context of this research as the ability to undergo change with relative ease upon demand. Flexibility may be modeled and valued using real options analysis (see for example Copeland and Antikarov 2001). A real option gives the decision maker the right, but not the obligation, to exercise an action or decision at a later time, thereby capturing the essence of flexibility. An important motivation for framing flexibility as a real option is to utilize algorithms for quantitative valuation of options in order to value flexibility.

This work focuses on the problem of how real options can be used for holistic decision making and architecting of socio-technical enterprises under uncertainty. The following two challenges guide this research:

1. Real options valuation has traditionally been applied to the valuation of business investment decisions under uncertainty (eg. Copeland and Antikarov 2001). More recently, real options methods have been applied to value flexibility in the context of system design (eg. Wang and de Neufville 2006, de Neufville 2003). Although real options analysis has been applied to different domains relevant to an enterprise, such as strategic investments and product design, there is no integrated framework that enables systematic exploration of 1) what type of flexibility, if any, is desirable, 2) how to enable flexibility and 3) where to implement flexibility in an enterprise.
2. Enterprises exhibit the emergence of silos that become isolated over time as complexity grows. Decision makers often exercise independent decentralized control within their division or silo. This model of decision making may suffer from local optimization within each of the silos, and give rise to conflicting decisions that reduce the enterprise performance. On the other hand, decision makers in a networked decentralized decision making architecture follow the "think globally, act locally" philosophy, giving consideration to factors outside of their respective silos that influence and will be influenced by their decisions. This is also referred to as integrating the silos in the decision making process. Recall that real options have been applied to different domains within an enterprise, ranging from engineering design to project investments. Traditionally, decisions regarding the different categories of real options fall within the expertise and authority of different decision makers within different silos of the enterprise. For instance, real options analysis in system design is the expertise of an engineering team, while real options in investments may be explored by executive managers. As in the case of independent decentralized decision making model, real options that are valued or implemented without consideration of factors or other options outside of their respective silos may lead to suboptimal means of implementing flexibility within enterprises.

This paper presents a conceptual foundation for addressing the above challenges. First, a new characterization of real options is introduced, motivated by the need for a more systematic exploration of real options opportunities in an enterprise. Prior work in real options is interpreted in the context of this new characterization. Second, a holistic model of enterprise architecture in terms of eight enterprise views and their dependencies is discussed. This model may be represented as a Coupled Dependency Structure Matrix (C-DSM) that has been shown to be useful in real options analysis (Mikaelian et al. 2007). Finally, the enterprise architecture model and the characterization of a real option introduced in this paper are used within a new real options framework, to support the holistic exploration and valuation of real options opportunities for enterprises.

Proposed Characterization of Real Options

A financial option is a financial instrument that provides the owner the right, but not the obligation, to buy or sell an underlying security at a specified price (referred to as the strike price), on or before the expiration date of the option (Cox and Rubinstein 1985). While financial options are precisely defined and parameterized, the definition of real options is more elusive. Real options are generally defined as the right, but not the obligation, to take an action or make a decision at a future time. At an intuitive level, real options capture the concept of flexibility. The term real option was first used by Myers (Myers 1984) in the context of strategic decision making. The word real refers to the fact that the underlying asset is real rather than financial. The idea in real options analysis is to quantitatively value investment decisions by taking into account the options that are available to the decision maker in the future. For instance, the ability to abandon a project and the ability to expand an investment in the future are two types of real options that must be taken into account when valuing the decisions of whether to invest.

Analogies have been made between financial and real options, mainly to justify the use of financial option valuation methods for valuing real options. However, analogies are typically weak because of many differences between financial and real options. The main difference is sometimes considered to be the fact that financial options and their underlying assets are tradable, while real options are not publicly traded. A major difference in the context of valuation is that a financial option has a clearly defined, fixed strike price, while it is not clear what the analogy of the strike price is in real options. Another difference is that a financial option has a clearly defined action (buy or sell stock at strike price) that can be exercised before the expiration date of the option. However, according to the above definition of a real option, any action or decision that may be taken in the future can be considered to be a real option.

As a first step towards the development of an integrated approach to real options analysis for enterprises, a new conceptual model of a real option is proposed. This conceptualization is shown in Figure 1. In this model, a distinction is made between two different sets of actions or decisions:

1. **Mechanism**: A mechanism is defined as the set of actions or decisions that either directly or indirectly enables a real option. An active mechanism is defined as a mechanism that directly enables a real option. For example, designing a modular payload bay for a mini air vehicle is an active mechanism that directly enables the flexibility to switch the type of payload. A passive mechanism is defined as a mechanism that indirectly enables a real option. For example, the decision to buy a plant is an indirect enabler of the real option to shut down the plant. It is not a direct enabler because the flexibility to shut down the plant already existed and buying the plant simply enables the owner to exercise this flexibility.
2. **Option Type**: The option type is characterized by the set of actions or decisions that may be exercised by the owner of the real option. For example, the option to switch the payload of a mini air vehicle, the option to abandon a project and the option to enter a new market are different types of options, referred to as an operational option, abandonment option and growth option respectively.

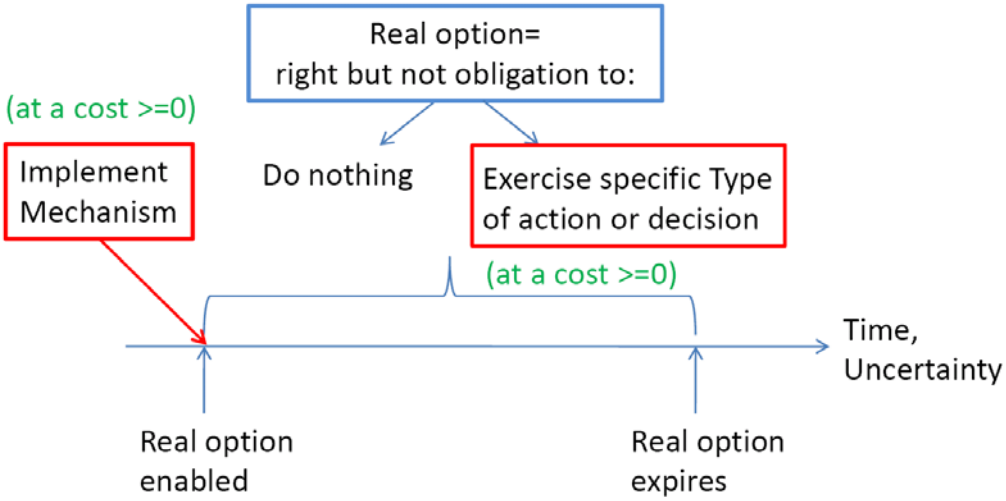


Figure 1: Anatomy of a real option.

While much of the prior work has focused on the classification of different types of real options, such as growth options and abandonment options, the conceptualization presented above identifies that there are two distinct sets of actions or decisions that relate to real options. One is the mechanism that enables a real option, and the second is the exercisable action(s) that are characterized by the type of the real option. Therefore, a new characterization of a real option as a tuple <Mechanism, Type> is introduced. For example, an interchangeable payload bay for a mini air vehicle enables flexibility to use the vehicle for a variety of missions. This real option can be characterized by the tuple <Design interchangeable payload bay, Operational option to switch to different payload>.

While different types of real options have been characterized in the literature, the conceptualization introduced in this paper also emphasizes real option mechanisms, which have not been systematically studied or characterized before. Although mechanisms are not part of the definition of a real option, they are important because they constitute sources or enablers of flexibility. Two distinct categories of mechanisms have been identified above: passive and active. Active mechanisms are especially interesting because they involve actions or decisions that directly enable real options, as opposed to passive mechanisms that involve the identification and exercise of existing options. For example, modularity in system design may be considered to be an active mechanism that enables flexibility in a system's function. Staged investment may be considered an active mechanism that enables the flexibility to either abandon a project with limited loss or continue into the next phase. While uncertainties facing an enterprise will guide the types of real options that best manage the uncertainties, knowledge of the principles and patterns of active mechanisms will guide the implementation of flexibility.

Real options in and on projects: Prior work has drawn a distinction between real options in and on projects. Real options "on" projects refer to strategic decisions regarding project investments (Copeland and Antikarov 2001). Real options "in" projects (Wang and de Neufville 2006) refer to engineering design decisions where design flexibility is valued in terms of future actions enabled by the designs. However, this classification is ambiguous because it does not specify whether it is the mechanism or the type of real option that is "in" or "on" a project.

Figure 2 shows a matrix of possible combinations of mechanisms and types of real options in and on a project. An example is given for each combination of mechanism and type of real option for a MAV (mini air vehicle) design project. A design change is a mechanism that is implemented in the MAV. A design change may enable a real option in a future design, such as the option to reuse the design. A design change may also enable a real option in strategy, which is an example of a real option on a project. The example given is a design change that enables the option to expand the market size by making the MAV functionality appealing to a different set of customers. An example of a mechanism on a project is a strategic partnership. A mechanism on a project may enable a real option in design. For example, the strategic partnership may provide the opportunity to leverage a new technology developed by the partner organization in the MAV design. Finally, an example of a mechanism on the project that enables a real option on the project is the decision to invest in a MAV project that in turn enables the option to expand this project later to a swarm of MAVs.

		Real Option Type	
		In	On
Real Option Mechanism	In	MAV design enables a reuse option in future design	MAV design enables future market expansion
	On	MAV development partnership enables option to use new type of technology in design	Investment in MAV project enables option to expand development to swarm in future

Figure 2: Examples of real option mechanisms and types in and on mini air vehicle (MAV) project.

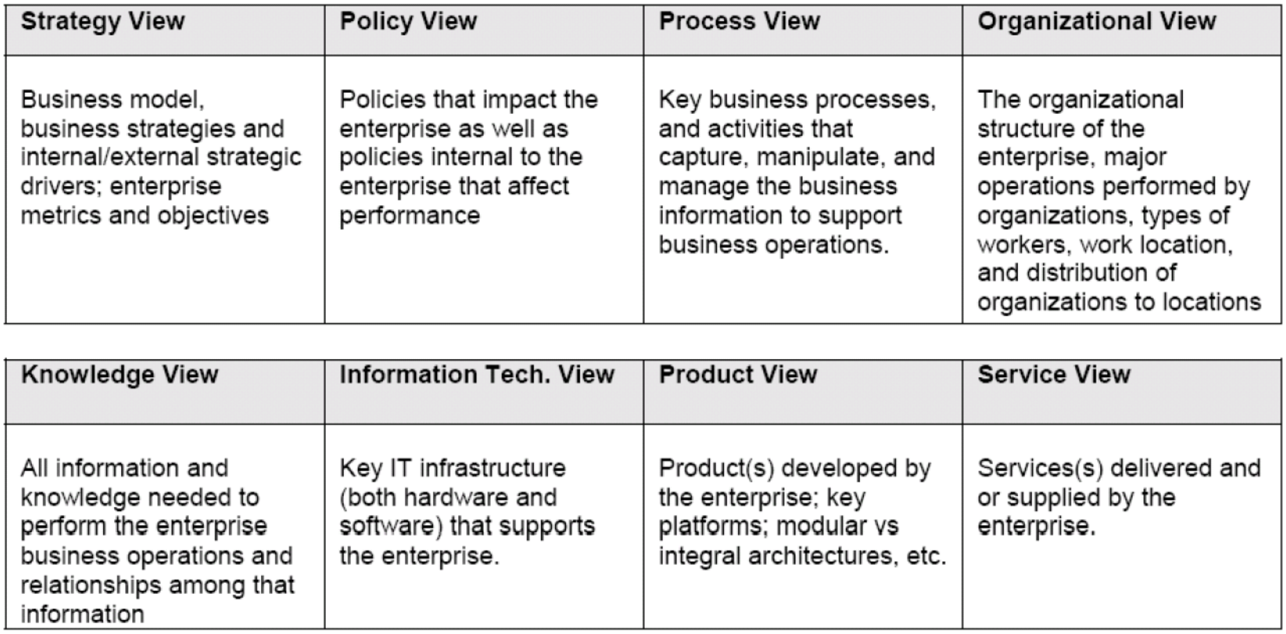
The above examples indicate that it is possible to classify the "location" (in this case the location is either in or on the MAV design project) of both the mechanism and type of a real option. This new classification reveals that different combinations of locations for mechanisms and types are possible, i.e. the mechanism and type of a real option do not both necessarily exist in the same “location”. Prior work has explored the question of where to insert real options in a system or project. Given the <Mechanism, Type> characterization of a real option, it can be seen that the question of where to insert real options consists of two distinct questions. The first is where to insert the type of real option, i.e. what type of flexibility is desirable. The second is where to insert the mechanism of the real option, i.e. how to enable the flexibility. An important implication of the proposed classification of real options is that different combinations of locations of mechanisms and types may systematically be explored to deal with uncertainties. For example, traditionally real options analysis may not have considered a strategic partnership as a mechanism on the project that enables a real option in system design (see Figure 2), whereas the new classification enables the explicit consideration of such an option. Therefore, this systematic classification may be leveraged to enable an integrated approach to exploring real options opportunities in an enterprise.

Enterprise Architecture

Within the context of this paper, an enterprise is a defined scope of economic organization or activity, which will return value to the participants through their interaction and contribution (ESD 2001). A socio-technical enterprise is defined as a technology intensive enterprise. In this paper, enterprise generally refers to a socio-technical enterprise.

The importance of information technology in enterprise decision making has led to the frequent association of enterprise architecture with the information technology (IT) architecture for the enterprise (Ross et al. 2006). As a result, many enterprise architecting frameworks have been developed to support IT investment decisions (Schekkerman 2004). However, enterprise architecture more generally refers to the structure and behavior of an enterprise. Since enterprises are complex socio-technical systems, it has been proposed that system architecture principles can be extended to the architecting of enterprises (Rechtin 1999). Nightingale and Rhodes (2007) define enterprise architecting as: "Applying holistic thinking to design, evaluate and select a preferred structure for a future state enterprise to realize its value proposition and desired behaviors."

Nightingale and Rhodes report that enterprises are often viewed through specific and narrow views (Nightingale and Rhodes 2004). Examples include the IT view that focuses on the IT architecture of the enterprise and the organizational view that focuses on organizational structure. In order to support a holistic approach to enterprise architecting as defined above, Nightingale and Rhodes propose a new framework that integrates the different views used to describe enterprise architectures. The eight views are strategy, organization, policy, products, services, processes, knowledge and IT. Each of the views is described in Figure 3. Furthermore, the views may have dependencies, examples of which are indicated by arrows in Figure 4. For instance, organizational structure is influenced by strategy. Note that the views and the relationships among the views may depend upon a given enterprise. Enterprise views and dependencies are proposed to be a means of describing the current (as-is) and future (to-be) architectures of an enterprise.



Strategy View	Policy View	Process View	Organizational View
Business model, business strategies and internal/external strategic drivers; enterprise metrics and objectives	Policies that impact the enterprise as well as policies internal to the enterprise that affect performance	Key business processes, and activities that capture, manipulate, and manage the business information to support business operations.	The organizational structure of the enterprise, major operations performed by organizations, types of workers, work location, and distribution of organizations to locations

Knowledge View	Information Tech. View	Product View	Service View
All information and knowledge needed to perform the enterprise business operations and relationships among that information	Key IT infrastructure (both hardware and software) that supports the enterprise.	Product(s) developed by the enterprise; key platforms; modular vs integral architectures, etc.	Services(s) delivered and or supplied by the enterprise.

Figure 3: Enterprise views (Nightingale and Rhodes 2007)

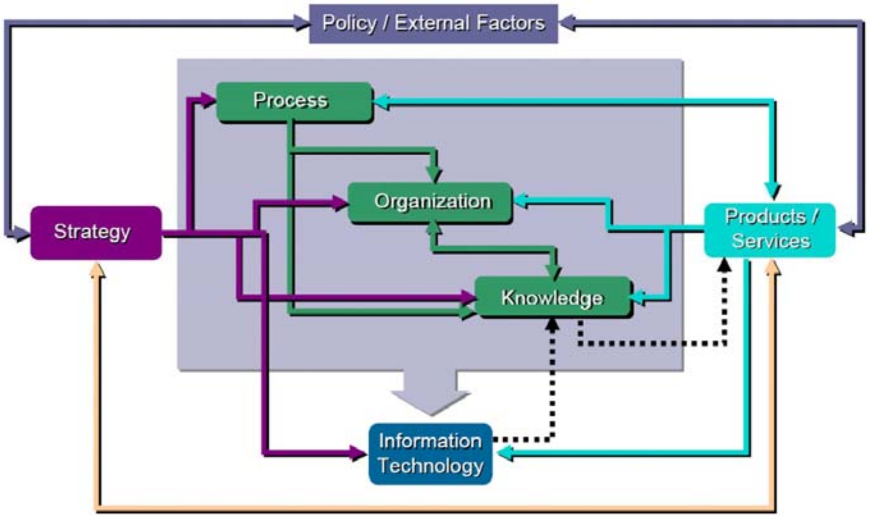


Figure 4: Examples of dependencies among enterprise views (Nightingale and Rhodes 2007)

Enterprise Architecture Representation: The enterprise views framework discussed above describes the different aspects of an enterprise, but does not specify how the information within each of the views and dependencies among the views are to be represented. Enterprise architecting frameworks have been developed and used in enterprise IT system implementations (Schekkerman 2004). However, these frameworks do not necessarily capture all views of an enterprise. Enterprise databases may contain a large amount of information, but not necessarily organized in a way that enables analysis and supports complex decision making. The information may be stored in various different formats, and varying amount of information from different enterprise silos may be available. Dependencies among the information in the databases may not necessarily be fully captured and represented. Finally, without a method to systematically identify and extract information that is relevant to a given decision maker, an enterprise database will be marginally useful. In order to address these limitations, (Bartolomei 2007) introduced a variant of a Coupled Dependency Structure Matrix (C-DSM) for representing complex systems projects. A Dependency Structure Matrix (DSM), also referred to as a Design Structure Matrix, is a matrix representation of dependencies within a single domain of a system, such as stakeholders, subsystems or activities. A Coupled Dependency Structure Matrix (C-DSM) is a larger scale model that includes multiple DSMs corresponding to different domains, as well as the relationships or flows among elements across these different DSMs. For a system development project, the C-DSM may be used to model dependencies ranging from stakeholders and their objectives, to system requirements, subsystems and development activities. This holistic view of the system is useful for change propagation, traceability and systems analyses.

The C-DSM representation may be adapted to represent information flows and dependencies within an enterprise. This involves creating a DSM for each of the enterprise views, as well as mapping the relationships among the views. The C-DSM framework has been shown to be useful in conjunction with real options analysis for system design, indicating that similar analysis may be performed at the enterprise level. For example, in (Mikaelian et al. 2007) a C-DSM representation of a mini air vehicle project was used to trace uncertainties to real options mechanisms in technical design. An enterprise C-DSM will leverage the full power of modeling socio-technical dependencies by recognizing that it may be possible to implement a solution beyond the technical domain, to encompass any of the enterprise views.

Real Options in Enterprise Architecture

Real options have found many isolated applications within enterprises. Figure 5 shows real options on and in projects as two isolated silos. This is because real options in projects involve design decisions that require technical expertise, while real options on projects are typically practiced by strategy analysts or higher level decision makers. However, real options valuated or implemented without consideration of factors and possibilities outside of their respective silos may lead to suboptimal mechanisms and types of flexibility within enterprises. The characterization of a real option as a tuple <Mechanism, Type> enables a more holistic approach to identifying real options opportunities, by considering that each of the mechanism and type of real option may be located in or on a project, thereby exploring the relations among the traditionally isolated real option silos. Furthermore, neither real options nor enterprises are limited to systems projects. For example, real options have applications in human resource management and organizational design (Badders et al. 2007, Dahlgren et al. 2007).

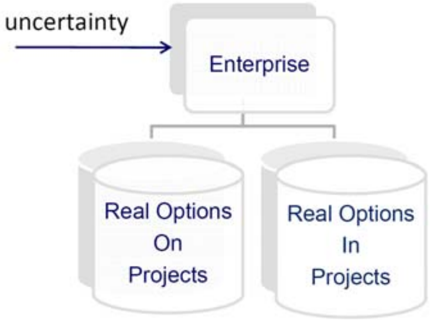


Figure 5: Real options applications on and in projects.

As discussed in the previous section, an enterprise may have a complex architecture that may be described by the various enterprise views. A holistic approach to real options exploration in an enterprise is introduced, by leveraging both the enterprise views and the characterization of a real option as a <Mechanism, Type>. The idea is that each of the mechanism and type may exist within any of the views of an enterprise. For example, modular design may enable: 1) the option of component reuse in a future design, 2) the option of different function during system operation or 3) the option of customization for market expansion. In this example, the mechanism is implemented in the product, and the real options are enabled in the product, operational process and strategy views respectively. Note that a single mechanism may enable one or more types of real options in possibly multiple views of the enterprise. Also, the set of actions in a mechanism may be distributed across different views of the enterprise. For example, both a change in design and a strategic partnership with an organization that can implement this design change may be essential to enable an operational flexibility provided by this new design. Figure 6 shows some examples of real options mapped to enterprise views. This classification of real options in an enterprise allows the systematic identification, mapping and exploration of existing and new combinations of mechanisms and types of flexibility across enterprise views.

Figure 7 lists some challenges facing an enterprise responsible for the development and operation of mini air vehicles, along with uncertainties facing these decisions. The challenges may be addressed through real options mechanisms and types mapped to various enterprise views. Two examples of operational options are 1) a design mechanism that provides an option to the MAV operator and 2) training of extra operators in order to enable the deployment of a larger network of MAVs. In each case, the mechanism and type of real option may be considered to span different views of the enterprise that develops and operates the MAVs.

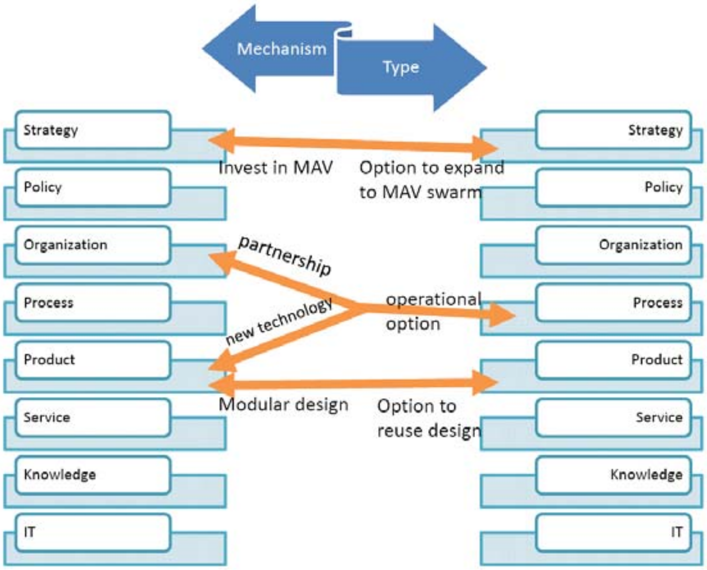
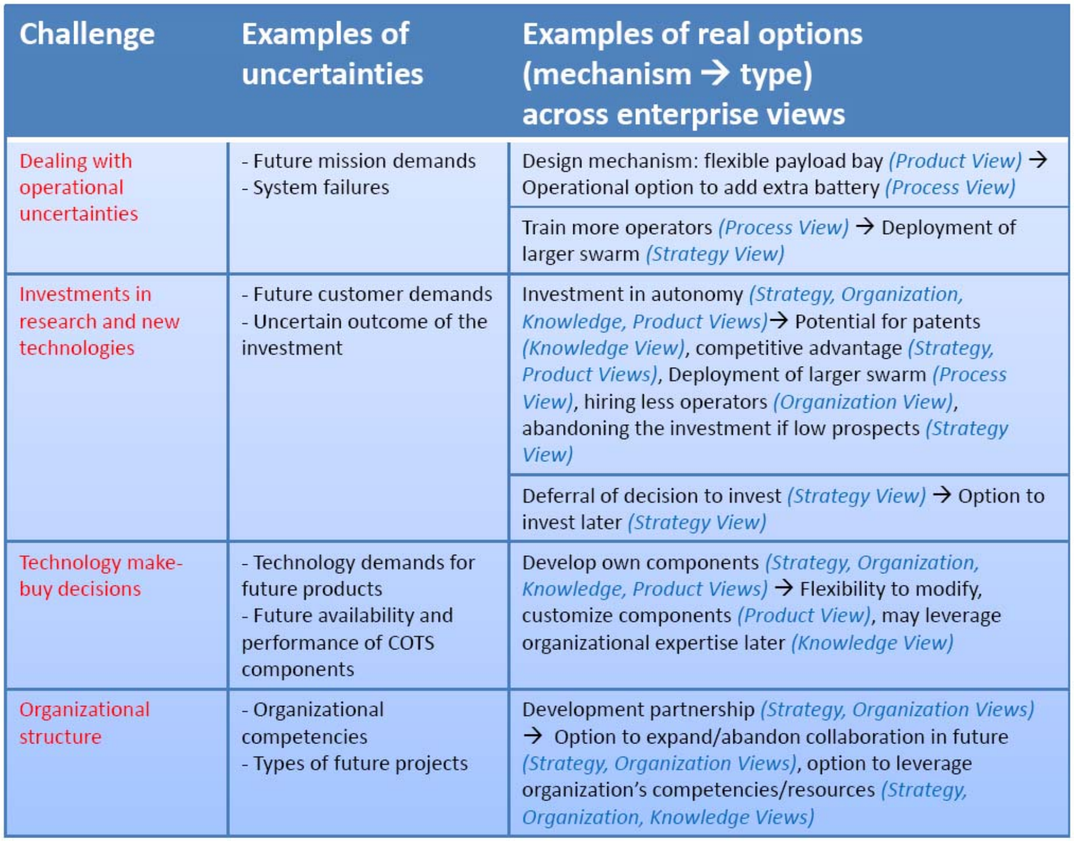


Figure 6: Some examples of mapping real options mechanisms and types to enterprise views.



Challenge	Examples of uncertainties	Examples of real options (mechanism → type) across enterprise views
Dealing with operational uncertainties	- Future mission demands - System failures	Design mechanism: flexible payload bay *(Product View)* → Operational option to add extra battery *(Process View)*
		Train more operators *(Process View)* → Deployment of larger swarm *(Strategy View)*
Investments in research and new technologies	- Future customer demands - Uncertain outcome of the investment	Investment in autonomy *(Strategy, Organization, Knowledge, Product Views)*→ Potential for patents *(Knowledge View)*, competitive advantage *(Strategy, Product Views)*, Deployment of larger swarm *(Process View)*, hiring less operators *(Organization View)*, abandoning the investment if low prospects *(Strategy View)*
		Deferral of decision to invest *(Strategy View)* → Option to invest later *(Strategy View)*
Technology make-buy decisions	- Technology demands for future products - Future availability and performance of COTS components	Develop own components *(Strategy, Organization, Knowledge, Product Views)* → Flexibility to modify, customize components *(Product View)*, may leverage organizational expertise later *(Knowledge View)*
Organizational structure	- Organizational competencies - Types of future projects	Development partnership *(Strategy, Organization Views)* → Option to expand/abandon collaboration in future *(Strategy, Organization Views)*, option to leverage organization's competencies/resources *(Strategy, Organization, Knowledge Views)*

Figure 7: Examples of challenges, uncertainties and potential real options across enterprise views.

A conceptual real options framework for enterprises is shown in Figure 8. A C-DSM model of enterprise views may provide the dependency information necessary for identification and valuation of real options. The exploration of mechanisms and types of options to deal with uncertainties may benefit from a catalog of patterns of mechanisms and types of options. Candidate mechanisms and types of real options may be mapped to enterprise views. Candidate solutions that neither implement mechanisms nor enable any types of options are referred to as baseline (inflexible) candidates. Real options valuation techniques provide a quantitative toolbox for comparing all identified candidates in order to recommend the solution that will generate the best outcomes under uncertainty. Once the decision is implemented, the C-DSM is modified to reflect changes to the enterprise architecture. This process may be applied continuously to stage the transformation of an enterprise and more generally to identify real options opportunities and evaluate decisions under uncertainty.

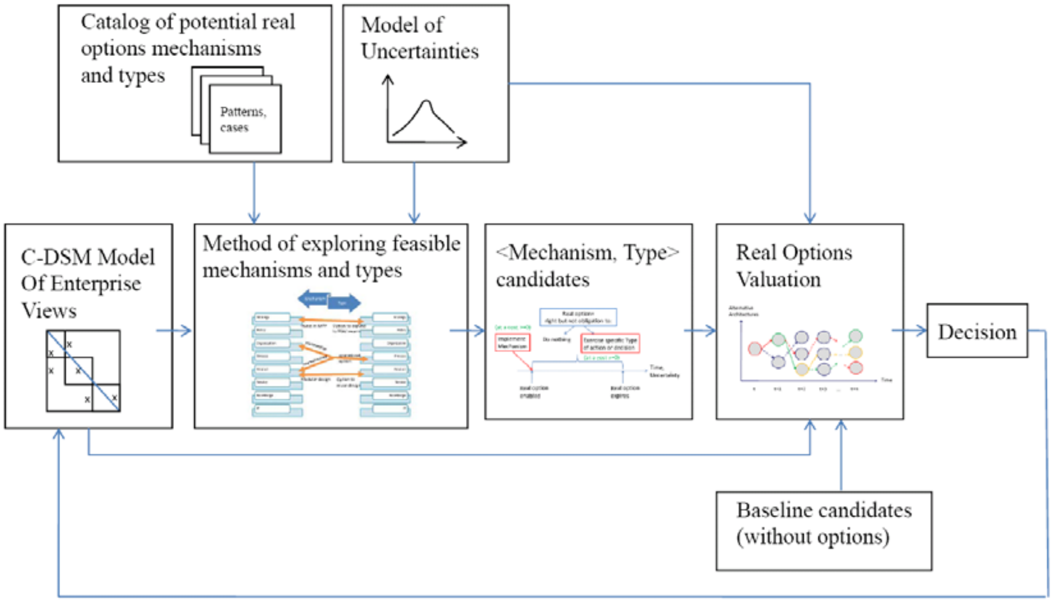


Figure 8: Integrated real options framework for an enterprise.

Conclusion

This paper introduced a conceptual real options based framework to support complex decision making within socio-technical enterprises. A new characterization of a real option as a tuple consisting of a mechanism and type is introduced. A new classification of real options based on the mapping of mechanisms and types of options to enterprise views is devised in order to enable active exploration of combinations of and dependencies among mechanisms and types of options that may encompass the enterprise views. The modeling of enterprise views and their dependencies as a Coupled Dependency Structure Matrix (C-DSM) is suggested, given the initial success of leveraging C-DSM models for real options identification. Future work includes identification and documentation of patterns of mechanisms that enable flexibility as well as the types of flexibility in an enterprise, development of an algorithm for using the C-DSM to identify feasible real options opportunities, and the application of a quantitative options valuation toolbox to study tradeoffs among alternative sources and types of flexibility.

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Biographies

Tsoline Mikaelian is a doctoral candidate in the Department of Aeronautics and Astronautics at MIT. As a member of MIT's Systems Engineering Advancement Research Initiative (SEAri), her current research focuses on uncertainty management for complex systems and enterprises, supported by Singapore's Defense Science and Technology Agency. Ms. Mikaelian has a Master of Science degree in Aeronautics and Astronautics from MIT, and a Bachelor of Science degree in Space and Communication Sciences from York University, Canada.

Donna H. Rhodes is a Senior Lecturer and Principal Research Scientist in the MIT Engineering Systems Division. Prior to joining MIT, Dr. Rhodes had 20 years of experience in aerospace & defense and commercial products, where she held senior management positions in several corporations. She is one of the co-founders of the MIT Systems Engineering Advancement Research Initiative (SEAri), directing its research program and advising graduate students. She also leads research in enterprise systems engineering for the Lean Advancement Initiative at MIT. Dr. Rhodes is a Past President and Fellow of INCOSE, recipient of the INCOSE Founders Award, and presently is director of the SEANET doctoral student network. She has published numerous papers and research reports in the field of systems engineering. Her research focuses on theory and practices for architecting and design of complex systems, systems-of-systems, and enterprises. She holds a M.S. and Ph.D. in Systems Science from T.J. Watson School of Engineering at Binghamton University.

Deborah J. Nightingale is a Professor of the Practice of Aeronautics and Astronautics and Engineering Systems and Co-Director of the Lean Advancement Initiative at MIT. Her research interests are focused on lean enterprise integration, enterprise architecting, and organizational transformation. She holds a Ph.D. in Industrial and Systems Engineering from The Ohio State University and M.S. and B.S. degrees in Computer and Information Science from The Ohio State University and University of Dayton, respectively. She is a Past-President and Fellow of the Institute for Industrial Engineers and a member of the National Academy of Engineering.

Daniel E. Hastings is the Dean for Undergraduate Education and a Professor of Aeronautics and Astronautics and Engineering Systems at MIT. Dr. Hastings has taught courses and seminars in plasma physics, rocket propulsion, advanced space power and propulsion systems, aerospace policy, technology and policy, and space systems engineering. He served as Chief Scientist to the U.S. Air Force from 1997 to 1999 and as Director of MIT's Engineering Systems Division from 2004 to 2005. He is a member of the National Science Board, the International Academy of Astronautics, the Applied Physics Lab Science and Technology Advisory Panel, and the Air Force Scientific Advisory Board.