Using System Dynamics to Extend Real Options Use: Insights from the Oil & Gas Industry

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Abstract

The current work examines the application of system dynamics to real options through work with a major energy firm to apply real options. Five key challenges facing the real options community are presented and potential system dynamics contributions to these challenges are discussed. Two cases from a BP research project illustrate how system dynamics can be used to develop and value real options. The work shows that the use of systems dynamics in real option development and valuation can 1) address key challenges facing the real options community and increase the use of real options in the oil and gas industry 2) allow system dynamicists to offer increased value in developing and valuing flexibility and 3) open system dynamics to new markets of research collaboration and potential clients.

Keywords: real options; flexibility; system dynamics; Georgetown Challenge

Introduction

Effectively using managerial flexibility to manage large oil and gas development projects is often critical to success. Real options theory is one means of structuring and valuing flexible strategies to address uncertainty. Real options allow strategy changes in the future based on how some uncertainty has been resolved. This flexibility can be an effective method of risk management, particularly in the oil and gas industry where capital intensive investment decisions must be made under great uncertainty (Armstrong et al. 2005, Woolley and Cannizzio 2005, Amram and Kulatilaka 1999a). Although conceptually appealing, exploiting the potential of real options to increase project value in practice has proven difficult. In particular, managers have been slow to adopt real options as a regular risk management practice.

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In this paper we describe insights from a BP research and development (R&D) effort to identify and address issues that influence the ability of project teams to use flexibility (real options concepts) to improve capital project outcomes. We first describe BP's business organization and the importance of large, capital investment projects. We then describe the ubiquitous influence of uncertainty on these major projects, discuss the theory and current BP reality of using flexibility to capture upside opportunities and avoiding downside risks by managing uncertainty, provide a brief description of System Dynamics applications to flexibility concepts, and then describe the Flexibility R&D project and business questions being addressed. We report findings that illustrate an important role for System Dynamics to extend the use of flexibility concepts within BP. One case shows how System Dynamics supports describing flexibility opportunities. A second case shows how a System Dynamics model can help communicate and quantify flexibility concepts. We draw conclusions and identify areas for System Dynamics applications and research. This paper should be of interest to those involved in helping organizations improve outcomes from investment opportunities by managing uncertainty.

Background

BP Capital Project Investment Environment

BP is a global energy group employing over 100,000 people and operating in over 100 countries worldwide. In order to delivery energy products and services BP's businesses are organized into three segments: Exploration and Production (E&P), Refining and Marketing (R&M), and Gas, Power, and Renewables (GP&R). The E&P segment takes oil and natural gas resources from discovery to development and production while R&M focuses on supply and trading, refining, marketing and transportation of oil and petroleum products. Finally, GP&R maximizes the value of BP's gas products by integrated marketing and trading of energy and energy solutions. In addition, BP Alternative Energy, launched in 2005 as part of GP&R, consolidates BP's low-carbon activities in a single power sector to pursue high-growth objectives in solar, wind, hydrogen power and gas-fired power technologies.

In order to achieve E&P development and production objectives, BP routinely invests in the design and construction of new production facilities. Due to the commodity nature of oil and gas, there is intense competition among industry participants to efficiently and safely build technologically advanced, safe facilities while balancing capital investment, operating costs, and availability. As stated in BP's update of 4th quarter results and strategies in 2004 (published 8 February 2005), BP will continue to make appropriate investment for long term growth at a rate of approximately $14bn/year capital expense in 2005-06, with approximately 70% occurring in the E&P segment. The magnitude of these E&P capital investments demands that appropriate tools and techniques be used to continuously improve the quality of decisions and thereby increase shareholder value.

BP performs extensive pre-project planning of its E&P projects to capture project value, including the assessment and selection of alternative strategies. Some project value is easy to recognize and relatively predictable, such as increased productivity from training or the potential of reduced costs with shorter project durations. Such value can be recognized and realized using traditional project management methods and tools. Some project uncertainties are small enough to allow the design, analysis, and choice of rigid strategies during pre-project planning. In these rigid strategies managerial policies do not respond to changes in uncertain conditions during the project. However, many E&P project conditions evolve over time and the conditions, times, and managerial choices for effective decision-making cannot be completely and accurately determined during pre-project planning. Additional data collection can sometimes improve descriptions of apparently large uncertainties enough to allow the design, assessment, and selection of alternative rigid strategies. But often uncertainties are too vague to effectively design, assess, and select among strategy alternatives before a project must proceed.

Significant project value may remain hidden, and therefore unexploited, in the uncertain portions of projects. Successfully conceptualizing, planning, designing, and executing a major energy project involves recognizing and effectively managing a wide range of uncertainties (Savage, Scholtes and Zweidler 2006). Simplistically, these uncertainties can be categorized in four separate but tightly coupled areas: resources, facilities, markets, and stakeholders. To illustrate, we focus on a hypothetical deepwater oil reserve in a remote area of the world where there is little or no energy infrastructure. Initially, the actual *resource* in place and ultimate reserves (those resources that can be economically produced) can only be estimated by integrating limited information from a variety of sources such as the discovery well, reservoir delineation drilling, seismic imaging, fluid samples, etc. This in turn impacts a wide range of drilling, production and export *facility* choices: number and types of wells (producer or pressure support), extent and type of production collection and distribution system (placed on seafloor or a surface facility, water disposal, gas injection, etc.), and type of export system (size and length of pipeline, number and type of shuttle tanker, etc.). Key *market* uncertainties would typically include the expected demand and price, which are dependant on the type of production and proximity to existing markets. Finally, *stakeholders* include government(s) and regulatory agencies, contractors, suppliers, partners, consumers, etc. Each of the stakeholders will typically have unique requirements and needs that must be satisfied and aligned.

Real Options Theory and Flexible Strategies: Promise and Reality

Real options theory is one means of structuring and valuing flexible strategies to address uncertainty. A real option is a right without an obligation to take specific future actions depending on how uncertain conditions evolve (Amram and Kulatilaka 1999a). The central premise of real options theory is that, if future conditions are uncertain and changing the strategy later incurs substantial costs, then having flexible strategies and delaying decisions can add value when compared to making all strategic decisions during pre-project planning. Real options theory attempts to answer the questions: "What are the future alternative actions?", "When should we choose between these actions to maximize value based on the evolution of conditions?", and "How much is the right to choose an alternative worth at any given time?"

Historically, real options theory is based on the approach developed to value and analyze options on financial assets (Bookstaber 1982, Cox et al. 1979, Black and Scholes 1973). Methods for valuing options specifically on real assets have since been developed and analyzed (Brealey and Meyers 2000, Trigeorgis 1993, 1995, Dixit and Pindyck 1994, Kemna and Vorst 1990), applied to engineering (Benaroch 2001, Baldwin and Clark 2000, Park and Herath 2000), project management (Ford et al. 2002), and promoted as a strategic planning aid by both academics (Miller and Lessard 2000, Amram and Kulatilaka 1999b, Bierman and Smidt 1992, Kensinger 1988) and practitioners (Leslie and Michaels 1997). The options approach has also been adapted to financial strategy (Trigeorgis 1993, Myers 1984). Real options have been used to capture latent value in many domains, including natural resources, research and development, technology, real estate, and product development (Benaroch 2001, Brennan and Trigeorgis 2000, Amram and Kulatilaka 1999a, Trigeorgis 1995, Dixit & Pindyck 1994, Kemna 1993).

The promise of flexibility concepts is particularly appealing to an energy company, like BP, where capital intensive investment decisions must be made under great uncertainty (Savage et al. 2006, Armstrong et al. 2005, Woolley and Cannizzio 2005, Amram and Kulatilaka 1999a). However, while conceptually appealing, exploiting the potential of real options to increase project value in practice has been mixed within BP after several years. While several successful applications can be documented, widespread knowledge, a common language, and consistent use of flexibility concepts within the projects community appeared to be low.

This initial view of flexibility practice within BP is not surprising considering the slow adoption of real options within many industries. In contrast to the expectations of some real options researchers (e.g. Copeland and Antikarov 2001) the theory is not widely used by practitioners. In 2002, a survey of 205 Fortune 1000 CFOs (Chief Finance Officer) revealed that only 11.4% use real options, while 96% use Net Present Value (Teach 2003). Researchers point to the traditional valuation methods that are complex and non-standardized as a reason for this difficulty (Triantis 2005, Borison 2005). Another survey found that many managers view real options as a strategic planning tool but do not use real options techniques to value flexibility (Triantis 2005). In what the real options community refers to as the “Georgetown Challenge,” Alexander Triantis, a leading real options researcher, directly addressed this issue. He outlined five challenges that must be met to take real options from an appealing theoretical concept to a useful practitioner’s tool: 1) refining the models of perfection, 2) splitting options, 3) modeling managerial behavior, 4) developing heuristics, and 5) valuing the whole firm (Triantis 2005 p. 11).

1) Refining the Models of Perfection: This challenge addresses the assumptions that current real options models are based upon. These assumptions are tied to models used to value purely financial assets. These include the assumption of a perfect market, viewing assets as liquid, managers who always seek to maximize value, uncertainty specifications that are consistent with valuation models, and the selection of risk discount rates (Triantis 2005). These assumptions can hinder the validity of applying option models to real assets because the conditions in which options are applied to many real assets in practice are not consistent with these assumptions. See Alessandri et al. (2004) and Garvin and Cheah (2004) for additional discussion on the impacts of these assumptions.

2) Splitting Options: Splitting options involves valuing options that are available to more than one entity. An example from the Pharmaceutical industry would be the development of a new drug. Several companies have the ability to develop a particular drug so the option of beginning or continuing the development of a specific drug does not lie with only one company. Shared options are not confined to one entity and can be shared across an entire industry. The option for an airline to expand service and capacity not only affects the airline but also airline manufactures and airports (Triantis 2005). Split options also exist within the oil and gas development, such as when multiple projects could develop a new technology. Developing methods for valuing these types of options has proven difficult.

3) Modeling Managerial Behavior: One key assumption of many real options models is that managers always make optimal decisions (i.e. decisions that maximize value for the company) when deciding to exercise an option. This assumption could be invalidated for several reasons, ranging from simple mistakes to incentive programs that are misaligned with maximizing value. A key research need involves developing organizational structures and compensation programs to promote value maximizing decisions (Triantis 2005). An alternative improvement effort would develop real options models that reflect actual decision-making. Ford and Bhargav (2006) identified project management as a common real option setting in which option designers and owners (the managers) behave to purposefully and successfully manipulate asset, and therefore option, values.

4) Developing Heuristics: As previously mentioned, current real option valuation models are mathematically complex and can be very intimidating for novice users. The experience of the authors in working with practicing managers in the oil and gas industry across many fields of expertise, levels of responsibility, and projects support this conclusion. Simpler models are needed, even if they lack some of the accuracy of more complex models. Triantis believes this includes modification of current Net Present Value (NPV) techniques and scenario and simulation analysis (2005).

5) Valuing the Whole Firm: Valuing and managing the firm involves linking real options on a firm's individual projects to investors and analyst company performance measures. The value of an option held by the company may not be adequately described by current company reporting practices (Triantis 2005). This makes unbiasedly valuing a firm that holds options difficult and potentially inaccurate.

The Application of System Dynamics to Real Options

The five issues in the Georgetown Challenge above identify areas of decision analysis that could be addressed by system dynamics. However, the documented use of system dynamics in real options application has been limited. Ford and Sobek (2005) used system dynamics to model product development at Toyota. They investigated how the use of options among multiple product designs during development affected project value. A system dynamics model simulated the simultaneous development of four alternative designs for an automotive subsystem. Multiple simulations were used to quantify the value of delaying alternative selection in the development process. The work showed that a real options approach can be adapted and operationalized to model design selection alternative. In the larger picture it demonstrated the ability of system dynamics to value real options.

Cooke (2004) used system dynamics to model Geometric Brownian Motion,[4] the Black-Scholes equation,[5] and mean reverting behavior.[6] The transparency of system dynamics modeling allows novice finance students to understand the intuition behind the equation. The author states the main contribution of the work as the ability “to show how many of the complex price processes that have been researched by scholars in Finance can easily be translated into system dynamics models” (p. 17).

While the authors believe that system dynamics can help real options transition from theory to practice, it is not the single solution to the challenges facing real options use. As will be shown, system dynamics is well suited to address several of the Georgetown Challenges, particularly in the area real option model assumptions, but it cannot solve all the challenges. Therefore, a central hypothesis of the current work is that system dynamics can be a valuable part of a toolkit for applying real options to practice in the oil and gas industry.

Problem Statement

Given this background, BP initiated the Project Flexibility R&D project to identify and address issues influencing the ability of project teams to use flexibility concepts to improve capital project outcomes. Consistent with BP R&D project planning and execution practice, BP employed a Technical Capital Value Process (TCVP) with five phases, a gatekeeper, and specific stage-gate decisions: Appraise; Select; Define; Execute; Operate. The Appraise activities generally confirmed initial impressions about

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[4] Geometric Brownian Motion can be used to describe the volatility of stock prices.
[5] The Black-Scholes equation is used to value certain financial options.
[6] Mean reverting behavior is often used to describe commodity prices.

the state of flexibility concept practice within BP and served as the basis for the decision to progress the project into the Select stage where a more rigorous investigation would be completed. Key objectives included: better documentation of the state of BP flexibility practice; development of appropriate guidelines and tools; development of an effective means of communicating flexibility concepts; and identification of a project willing to pilot test planned guidelines and tools.

The 2005 Project Flexibility R&D Select phase activities were organized to answer, or at least develop insight into the following representative business questions:

- What is the existing practice with respect to real options?
- What do practitioners find difficult about flexibility?
- What tools are used when flexibility is used to manage uncertainty and why?
- How do project teams think about and talk about flexibility concepts?
- How integrated are flexibility concepts in risk management practices?
- How has flexibility been use in the past?
- How can the future development of flexibility be improved?
- How can the system dynamics methodology and tools support the use of flexibility?

BP decided to team with researchers from Texas A&M University to take advantage of common research interests and a synergistic working relationship developed over the last several years. To address the Project Flexibility R&D objectives we jointly conducted a series of interviews, developed prototype processes and tools, and developed several system dynamics simulators. The remaining portion of this paper focuses on two BP project examples of effective flexibility practice.

The first case describes how a project manager used flexibility to effectively manage resource uncertainty and its influence on facility development plans in a new field development. This case allowed us to clearly identify the linkages between system dynamics methodology and the need for project managers to adequately structure flexibility opportunities. As a result, we developed a prototype of a simple tool for describing flexibility and obtained feedback from project managers on its perceived usefulness. The second case describes how a project manager used flexibility to effectively manage the uncertainty around a rapidly closing summer sealift transportation window and the delivery of a key piece of equipment. We used this case to develop a simple system dynamics simulator to communicate and value flexibility concepts.

BP Project Flexibility R&D Select Stage: Early Findings

Observations of the use of flexibility that can be structured as real options in the planning and management of oil and gas development projects reveal several critical strategy development process steps, including:

- Structure a complex dynamic problem
- Visualize and use scenarios to describe possible futures
- Map project drivers to performance
- Predict project performance under different strategies
- Explain performance using the problem, project, and strategy descriptions

Although project managers may not realize they are developing flexibility through the use of a real option, our field work indicates that they have an understanding of the value of this flexibility within their project. The following case illustrates this concept.

Case I: Resource Uncertainty and Facilities Planning

Reservoir Two is a new hydrocarbon field adjacent to Reservoir One, a large existing developed field with several years of production history.[7] Based on the limited data gathered while discovering and initially sizing Reservoir Two, the new field was projected to have reservoir characteristics similar to Reservoir One. An economic analysis supported a decision to pursue an aggressive and expensive full-field

[7] The example is based upon an actual situation encountered by a BP project team. The information has been disguised to maintain confidentiality while retaining the important characteristics of the situation.

development of Reservoir Two. Front End Engineering and Design (FEED) was initiated as well as a parallel effort to pre-drill several wells so that production could be quickly ramped up once construction was complete. But results from the early pre-drill wells revealed that Reservoir Two's characteristics were dramatically different from those of Reservoir One and Reservoir Two's reserves (available resources) might be much less than originally thought. Based on the new information and additional studies the initial full-field development plan was not economically viable due to uncertainty associated with average expected well production rates and reserves. The analysis surfaced important questions relating to what level of new field development, if any, would make economic sense. The project team was under significant pressure to initiate production quickly to prevent the loss of leases and subsequent investment write-down.

We applied a real options structuring tool to model the available strategies. The Reservoir Two project team had two basic development strategy alternatives after the disappointing pre-drill well information: abandon Reservoir Two and write off all costs to date or take the risk that the uncertain reserves were large and the big development plan would be economically feasible. Selecting either of these strategies based on the pre-drill information alone would make it very expensive to change to the other strategy later. What the team ***really*** wanted to do was to postpone their selection of a development strategy until they had more and better information about Reservoir Two. Given the uncertainties in the amount of reserves and potential profit, developing the improved information also had to be economically feasible.

The Reservoir Two project team needed a development strategy that could develop the reserves profitably even if those reserves were limited, allow abandonment without large sunk costs if the reserves were not available for reasonable costs, and not prevent expansion of development if the reserves turned out to be large. To address this challenge the team prepared a third, flexible strategy. The project team adopted a smaller-cheaper approach by slowing development drilling, renting surface production facilities, and trucking products to market instead of building a pipeline. This approach also allowed production of Reservoir Two to start earlier, thereby initiating revenues that offset development and production costs. While the rental choice had higher monthly operating costs, it allowed BP and its partners to delay higher capital investments while they reduced the uncertainty associated with the reservoir characteristics. This strategy also allowed a relatively inexpensive abandoning of the field if those wells did not produce adequately, and continued or expanded development if they did. This option can be structured in the following form (Figure 1)[8]:

The challenge that this project is facing is the economic development of Reservoir Two. The metric used to measure the performance in addressing this challenge is the economic value of Reservoir Two. The uncertainty that is causing this challenge is *the reservoir characteristics. The traditional approach to this challenge is to abandon the project and write of the investment. A possible alternate solution to this problem is to use a smaller-cheaper development to collect information. The performance measurement that can be used to evaluate the strategies is the volume of producible reserves. The value of this measurement that justifies switching from the traditional strategy to the alternative strategy is the minimum economically viable reserve level. In order to have the ability to change strategies we must produce the existing wells. To change strategies we would expand field development.*

Uncertain performance measure	Reservoir Two economic value
Driver of performance uncertainty	Reservoir characteristics
Reference strategy	Abandon project
Alternative strategy	Expand development
Signal for changing strategy	Forecasted reserve size
Conditions for strategy change	Minimum reserves for positive NPV for expanded development
Actions required to obtain or retain flexibility	Produce existing wells in economically feasible way
Action required to change strategy	Expand development
Decision rule for changing strategy	IF (the amount of forecasted reserves) > (minimum reserves for positive NPV for expanded development) THEN (expand development) ELSE (abandon project)

Figure 1: Structure of an Option to Develop Reservoir Two

The description and conceptual modeling of developing Reservoir Two illustrates how real options thinking can help structure complex projects[9]. In addition, several process steps illustrated with the Reservoir Two example resemble processes and tools in the

[8] This description of the real option applies a structured strategy description tool developed by the authors.
[9] The structure shown in Figure 1 is not the only description possible for this strategy set. For example, the strategies could also be modeled as a pair of options to change from small scale development, one to abandon Reservoir Two and the other to expand development.

system dynamics methodology. Table 1 links flexible strategy development practice and the system dynamics methodology using the Reservoir Two example.

Flexible Strategy Development Practice	**Reservoir Two Example**	**System Dynamics Methodology** (Sterman 2000)
Structure a complex dynamic problem	Economic viability of field depends on amount of development and development methods	model boundary diagram, subsystem diagrams, (pp. 97-99)
Visualize and use scenarios to describe possible futures	Predicted large, limited, or no reserves and development	Reference mode diagrams (p. 90)
Map project drivers to performance	Project team modeled how reservoir characteristics and development costs impact economic viability	Subsystem diagrams, causal loop diagrams, stock and flow diagrams (pp. 99-102)
Predict project performance under different strategies	Project team estimated costs, production, and economic viability for development strategy / scenario sets	Formal system dynamics model (ch. 8-21)
Explain performance using the problem, project, and strategy descriptions	Project team justified flexible strategy based on development structure, scenarios, and strategies	Sensitivity analysis (pp. 883-7), dominant structure analysis (p. 897), model transparency (p. 62)

Table 1: Use of Flexibility in Practice and System Dynamics Methodology

The adoption of system dynamics tools and methods like those above may be able to improve the application of real options in practice. The Reservoir Two team did not explicitly apply the system dynamics tools listed in the right side of Table 1 to the Reservoir Two project. Instead they used traditional informal flexibility development tools. The researchers believe that Reservoir Two would have benefited if they had used the system dynamics tools outlined on the right side of Table 1. In addition to aiding the strategic planning process, system dynamics formal models can be used to value the flexibility incorporated into strategies as real options (e.g. Ford and Sobek 2005), as is illustrated in the following example.

Case II: Transportation Weather Windows and Equipment Delivery

The Project Isolated[10] case illustrates the potential use of formal system dynamics modeling for real options valuation. Project Isolated is a new development in a remote

[10] The example is based upon an actual situation encountered by a BP project team. The information has been disguised to maintain confidentiality while retaining the important characteristics of the situation.

location requiring a specialized piece of equipment that is only available from one manufacturer. Once equipment manufacturing is complete it will be transported by sealift from the manufacturer to the project location. However, the Project Isolated site is only accessible by sea during a short time window due to weather. The Project Isolated team is concerned that the manufacturer will not complete the equipment in time for delivery to the site by sealift within the available time window. If this window is missed, the next available window is several months later. This would significantly delay the development of Project Isolated and therefore severely degrade project performance. The project team is considering purchasing an option to transport the equipment by a more expensive airlift to avoid missing the weather window. This option can be structured as follows (Figure 2)[11]:

The challenge that this project is facing is a possible delay in the start of production. The uncertainty that is causing this challenge is the delivery of equipment to the Project Isolated site. The traditional approach to this challenge is to use a sealift to deliver the equipment. A possible alternate solution to this problem is to airlift the equipment to the Project Isolated site. The performance measurement that can be used to evaluate the strategies is the forecasted delivery date of the equipment by sealift. The value of this measurement that justifies switching from the traditional strategy to the alternative strategy is the required equipment delivery date (close of the weather window). In order to have the ability to change strategies the Project Isolated team must reserve airlift capacity and design the equipment to be airliftable. To change strategies the Project Isolated team would cancel the sealift and notify company of airlift.

Uncertain performance measure	Start of production
Driver of performance uncertainty	equipment delivery date
Reference strategy	sealift equipment
Alternative strategy	airlift equipment
Signal for changing strategy	forecasted delivery date of the equipment by sealift
Conditions for strategy change	End of weather window
Actions required to obtain or retain flexibility	reserve airlift capacity in advance, design equipment for airlift
Action required to change strategy	cancel sealift, notify airlift company
Decision rule for changing strategy	IF (forecasted delivery date) > (required delivery date) THEN (airlift equipment) ELSE (sealift equipment)

Figure 2: The Structure of an Option to Airlift Equipment

The project team wants to know how much they should be willing to pay to reserve the airlift alternative.

[11] This description of the real option applies a structured strategy description tool developed by the authors.

Model Description

System dynamics can be used to effectively model systems that drive option values because of its ability to model the impacts of the "unprecedented number of interdependent risk" that Savage et al. (2006) recognize must be managed by petroleum and other firms. To estimate the value of the airlift a system dynamics model was developed to simulate the manufacture and delivery of the equipment and value of the option.

The simulation model used here maps the backlogs and flows of work, resources, and information in an equipment manufacturing process and values the project. The model is organized into three sectors: Manufacturing; Managerial Flexibility & Asset Operations (Figure 3). Although the Managerial Flexibility sector and Asset Operation sector were modeled using Vensim, the Manufacturing sector is the only sector that contains significant traditional system dynamics features (i.e. feedback and delays).

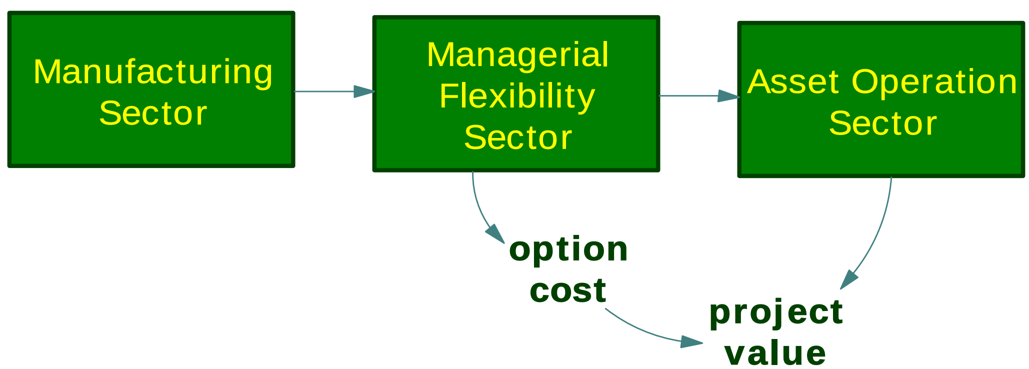

Figure 3: Model Sector Diagram

The Manufacturing sector (Figure 4) simulates the manufacturing and quality control activities for the new piece of equipment. Many processes, resources, management, and behaviors of project participants interact to drive performance. However, in the current work, only those features required to describe one specific way in which manufacturing can impact the value of flexibility, the completion date of manufacturing, are included. Manufacturing tasks that must be completed begin in the stock "Known Manufacturing

Scope Backlog" on the left side of Figure 4. Manufacturing tasks can be completed correctly and flow into the "Correct Manufacturing Work" stock or they can be unknowingly completed incorrectly and flow into the stock of "Undiscovered Manufacturing Rework" on the right side of Figure 4. Once the undiscovered rework is identified it flows into the stock of "Known Manufacturing Rework Backlog" until the errors are corrected. These corrected tasks are either completed correctly or incorrectly and flow into their respective backlogs. "Manufacturing scope change" represent equipment design changes that introduce new tasks after manufacturing has begun. The "manufacturing work flow" is constrained by either resources or process and restricts the completion of manufacturing work and rework.

This structure specifically accounts for the rework identified by quality control process and tracks fraction of original scope completed correctly. Therefore, the structure of the manufacturing portion of the model is significantly less complex than actual manufacturing processes. Therefore the model is considered useful for comparison, developing insights, and as a demonstration tool but not sufficient for strategy development. However, the manufacturing sector of the three sector model (Figure 4) could be improved or replaced with a more complete model to facilitate strategy development.

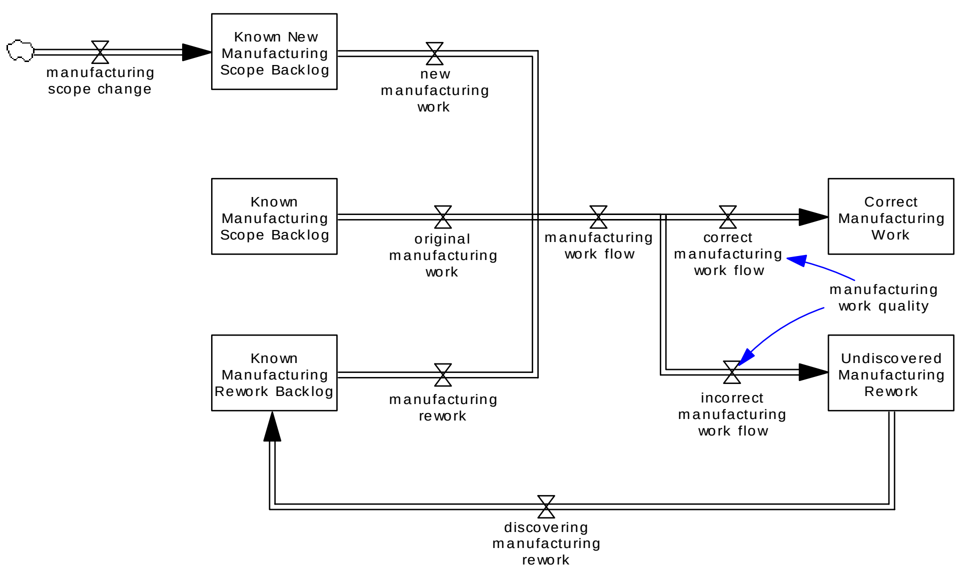

Figure 4: Manufacturing Sector

The Managerial Flexibility sector models the information that the project manager uses to monitor planned and actual manufacturing performance, the decision rules for executing flexibility choices, and the resultant transportation time. The Asset Operations sector models the asset oil reserves and production that is achieved, with and without project flexibility to account for manufacturing quality and its impact on schedule. Finally, the expenses (including option cost) and revenue are tracked and used to calculate the net present value of the project cash flows cash flows. Complete model equations are available from the authors.

To value the option, multiple simulations of a set of possible future scenarios were run with and without the air transport option. Total project transportation costs and revenues are averaged across scenarios to find expected values. In contrast to option valuation in perfect markets where it is assumed that the market will always match price (in this example cost of flexibility) to value, the option value and cost here may differ significantly. In the cast study modeled the approximate costs to obtain the option ($500,000) and exercise the option ($2,000,000) are known. Therefore we model the value added to the project by the option i.e. the **net** value of the option. The net value of the option (V_n) is modeled as the difference between the expected project value if the option is not available and the project value (including option costs) if the option is available:

$$V_n = E[P_O] - E[P_{NO}] \tag{1}$$

Where:

E[] – expected value operator

V_n – Option value [dollars]

P_{NO} – Project value if no option is available [dollars]

P_O – Project value if the option is available [dollars]

If the model for estimating manufacturing completion dates and costs accurately reflects Project Isolation, and the net option value is positive, then the option is more likely than not to add value to the project by allowing production to begin sooner than if the option was not available. In contrast, if the net option value is negative the option would not (on average) allow earlier production and therefore not add value to the project.

Model Testing

The model was calibrated based on the authors's understanding of the Project Isolation case and data collected from the Project Isolation project manager. A select set of standard tests for system dynamics models (Sterman 2000) were applied to develop confidence in the model's ability to reflect the fundamental manufacturing processes and project valuation, including units consistency, extreme conditions testing, and reasonable behavior testing.

The model generates reasonable behavior and consistency with options theory (Brealey and Meyers 2000) in valuing options across changes in some option features. Figure 5 presents simulation results for project net present value (NPV) for different manufacturing competition dates. Model inputs represent a transportation window closure at week 30 with a sealift transportation time of 5 weeks (i.e. equipment manufacture must be complete by week 25 in order to use the sealift option and avoid the weather window delay).

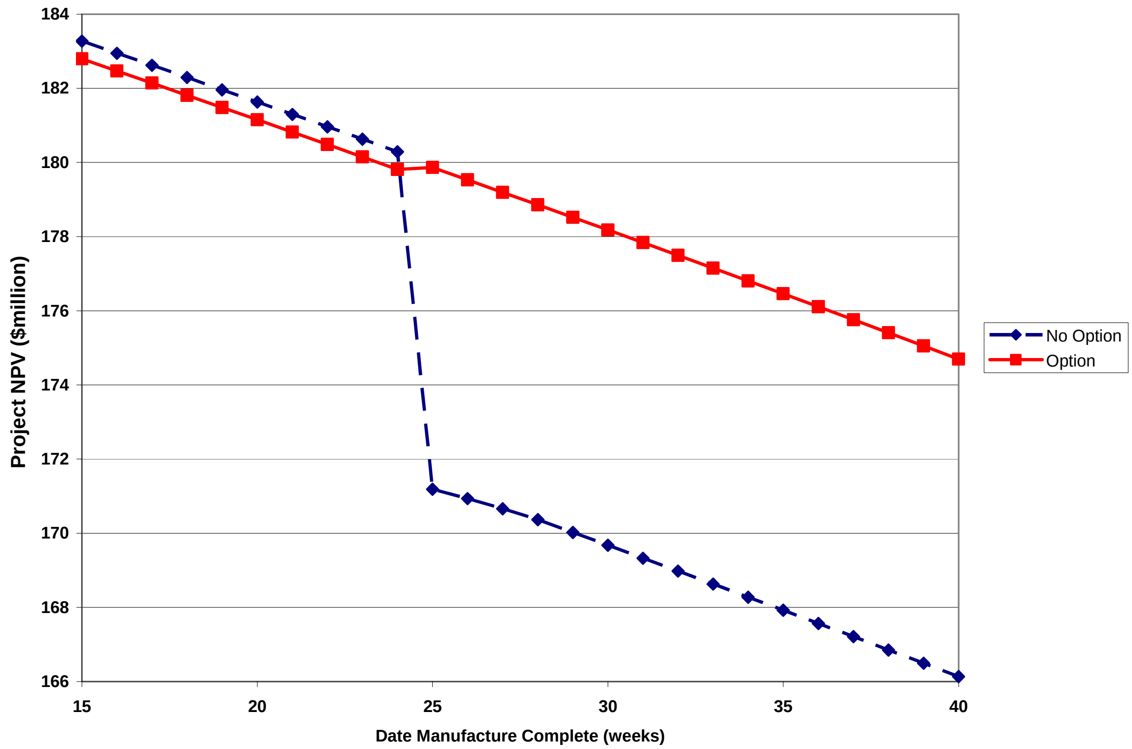

Figure 5: Project Value for Various Manufacture Completion Dates

Notice for projects whose equipment manufacture completion date is prior to week 25 in Figure 5, the no option project has a higher value then the project with the airlift option because these projects are not burdened with the unneeded option purchase costs. The project NPV difference between the option and no option projects prior to week 25 is $477,000, which is approximately equal to the cost to reserve the airlift option ($500,000).[12] For these scenarios, projects with the airlift option are less valuable than projects without the airlift option. This is expected since in these cases the airlift option was not exercised. In contrast, projects whose equipment manufacturing completion date is after week 25 are more valuable with the airlift option then without because the option is exercised. As previously discussed the difference between the project NPV with the airlift option (solid line in Figure 5) and without the option (dashed line in Figure 5) is the value of the option.

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[12] The difference between option and no option project NPV is not exactly equal to the airlift option cost due to the time value of money.

Based on testing the model is considered useful for the current investigations.

Model Use

The nature of the uncertainty in the descriptor of performance (manufacturing completion data), as reflected in its distribution of values, largely drives option value. Therefore, improving the accuracy of those distributions improves the valuation of flexibility. Real options valuation modeling traditionally takes this distribution as an input and assumes that it reflects the behavior of the system. However, little data is typically available on these variables and simple distribution shapes and values are often assumed. *System dynamics models of the systems that drive performance can potentially improve option valuation by improving the accuracy of performance distributions or the confidence that modelers have in those distributions.* To test the potential of system dynamics models to improve option valuation in this way the airlift option in the Project Isolation case was valued in two ways: 1) with a commonly assumed distribution to describe manufacturing performance and 2) with a system dynamics model of the manufacturing process with a single uncertain component. If the manufacturing process as modeled with the system dynamics model generates a different performance distribution than assumed for performance the resulting option valuation may also differ significantly, supporting the importance of modeling the drivers of option value with system dynamics models.

The equipment manufacturing completion date is the performance metric for the manufacturing process. In the system dynamics model of equipment manufacturing uncertainty is modeled with the fraction of manufacturing work requiring rework. The ability of the manufacturer to complete the project at the desired completion date is dependent upon the uncertainty associated with the manufactures work quality. If the manufacturer experiences relatively low levels of rework during the manufacturing process the equipment will be completed earlier, allowing the use of the original sealift transportation plan. However, if the manufacturer encounters high levels of rework the project is unlikely to meet the planned completion date and will be forced to use the airlift alternative (if it is available) or delay the project. For simplicity and illustrative purposes, it is assumed that the uncertainty in the rework fraction is reflected in a standard normal distribution with a mean value of 75% of the work requiring rework, a standard deviation of 5%, and a range of 0-100%. To facilitate comparison and isolate the impacts of the system dynamics model the assumed manufacturing completion date is also a standard normal distribution, in this case with a mean value equal to the mean date simulated with the system dynamics model (25.8 weeks) and a 5% standard deviation. A frequency distribution of the manufacturing completion date with a normal distribution and with the system dynamics model for 1000 simulated projects is shown in Figure 6.

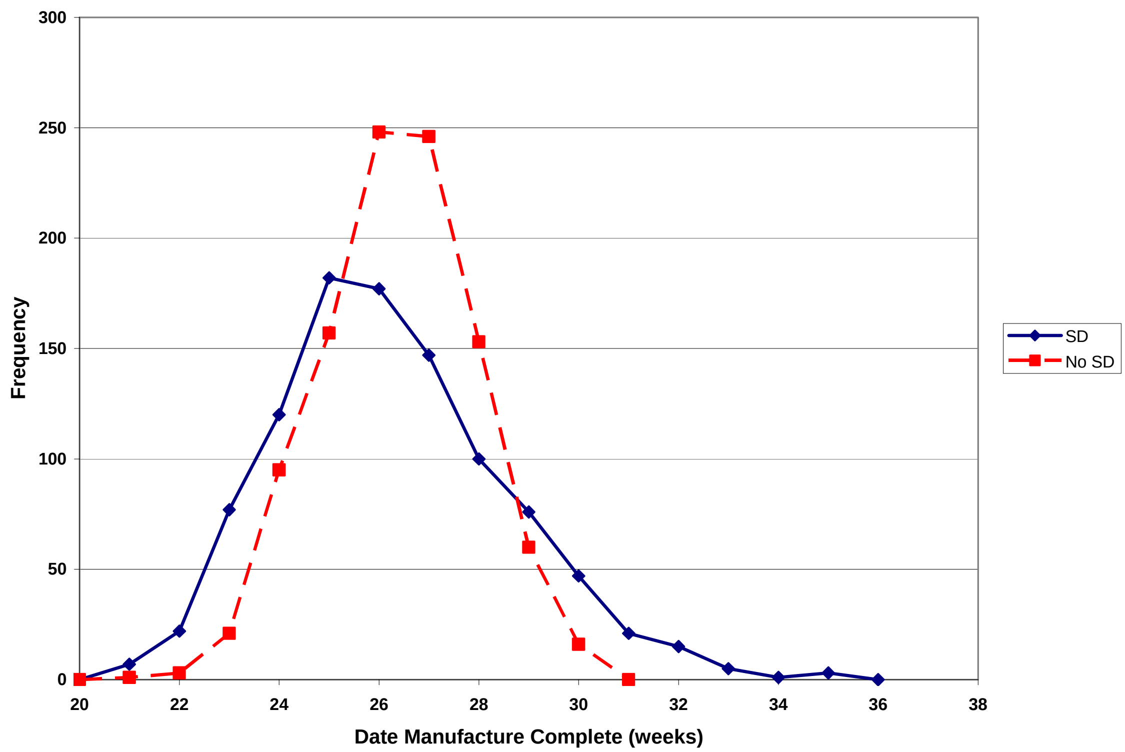

Figure 6: Distribution of Manufacturing Equipment Completion Date

The system dynamics manufacturing process, as modeled, changes the uncertainty in the performance metric (manufacturing completion date) from a standard normal distribution into a distribution that is skewed despite the fact that both distributions have the same mean. The smaller variance in the distribution without the system dynamics model is consistent with known biases in human estimates of distributions (Spetzler and Holstein 1975) The two distributions shown in Figure 6, along with the effect the option has on the mean transportation completion date, are described in Table 2.

Forecasting Method	Mean Date Manufacture Complete[13]	Stdev Date Manufacture Complete	Airlift option available?	Mean Date Transport Complete	Improvement in Mean due to Option	Stdev Date Transport Complete	Improvement in Stdev
SD	25.824	2.313	N	47.457	19 weeks (40%)	14.241	12 weeks (89%)
SD			Y	28.397		1.566	
No SD	25.952	1.502	N	51.156	23 weeks (45%)	11.939	11 weeks (90%)
No SD			Y	27.973		1.168	

Table 2: Manufacture and Transportation Completion Dates

Table 2 shows that for both simulation types (SD or No SD), the option reduced the mean transportation time by at least 40% and reduced the standard deviation of mean transportation time by at lease 89%. Despite the size of these impacts Table 2 reflects only part of the impact the airlift option has on the equipment transportation time. The airlift option reduces the mean transportation time by transforming the transportation completion date distribution from a bimodal distribution to a single modal distribution, as shown in Figure 7. These modal changes are considered critical in system dynamics (Sterman 2000) and can greatly influence other project features.

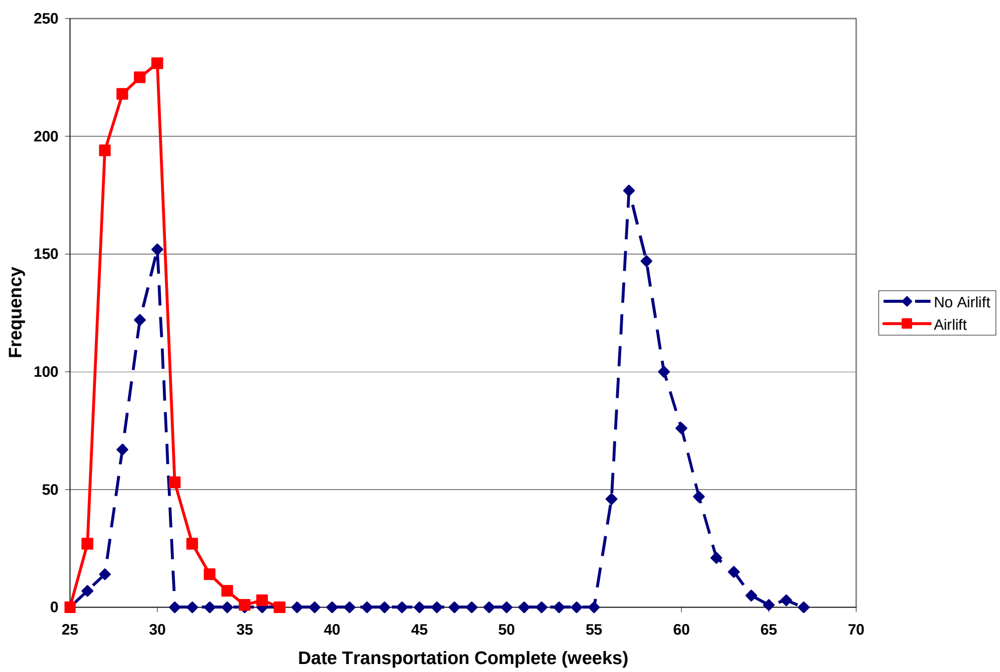

Figure 7: Distribution of Transportation Completion Dates

[13] The mean date manufacturing complete is not identical for both SD and No SD due to the limited number of simulations (1,000) performed.

These changes in the transportation completion dates affect the net present value of the project (Table 3).

Forecasting Method	Airlift option available?	Expected Project NPV ($million)	Net Value added by Flex ($million)
SD	N	174.192	5.338
SD	Y	179.530	
No SD	N	172.947	6.605
No SD	Y	179.552	

Table 3: Value of Flexibility

The net value added by the airlift flexibility for both simulation methods is approximately 3% of the total project NPV. Thus, by purchasing the airlift option for $500,000 the Project Isolated team would increase the expected project value by $5-6 million. These results are consistent with the decision of the project manager in the actual project who noted that the decision to purchase the air lift option was a "no-brainer" as it greatly reduced the risk of a major project delay and added value to the project.

Table 3 also shows how the slight difference in the equipment manufacture completion time distributions (Figure 6) can affect the net value added by the airlift option. Using system dynamics to estimate the distribution of manufacturing completion times yields an option value of $5.4 million while using a random normal distribution to estimate the manufacturing completion dates yields an option value of $6.6 million, a difference of approximately 20%. If the system dynamics model accurately reflects the manufacturing process, the Project Isolated team may have overvalued the option if they used the random normal distribution assumed here to represent the equipment manufacture completion date uncertainty. This highlights one of system dynamics key opportunities in real options valuation.

The Project Isolation case illustrates the ability of system dynamics to value real options potentially more accurately than using simple assumptions about uncertainty and in a transparent explanatory model of the potential benefits of effective real options use. The two cases described above can be used to show how system dynamics can help meet the challenges put forth in the Georgetown Challenge.

Discussion

The Reservoir Two and Project Isolated cases show that some project teams within BP recognize the importance of flexibility in project success. Several project managers indicated that the difficulty in retaining flexibility is justifying increased expenses that may not ultimately add value to the project (as described above). Although BP has a dedicated real options group that can value flexibility, current valuations techniques are not well understood by project teams and managers who must approve capital budgets. This has limited the use of real options within BP and supports Triantis's challenge to develop simple heuristics for option valuation.

Most of the project managers interviewed in Project Flexibility had been exposed to the use of decision trees and Monte Carlo analysis techniques to develop and value flexibility. In practice, only the most simple decision trees are used. In addition, a limited number of the project managers had been exposed to the DPL software that uses decision trees to help visualize and describe real options. The commercially available DPL software is designed to value and compare the real options by integrating with the Excel® discounted cash flow (DCF) model used by the project commercial support team. The use of DPL is not part of the current BP practice due to the need to involve an expert in the use of the software and the lack of confidence with the many probability distribution functions (PDF) that have to be guessed at in order to populate a DPL model. This supports the use of system dynamics models that can provide more confidence to managers. Regardless of the tool used, there was a common theme that there is always a great deal of skepticism introduced with complex decision trees and when a solution is based on Monte Carlo analysis due to the lack of transparency and mistrust of the PDFs.

While the use of system dynamics within BP has been increasing over the past several years, its use has not become common place. This is in large part due to the unfamiliarity of project team members with system dynamics. The Project Isolated example and model provides both system dynamicists and real option proponents within BP a tool that can demonstrate both system dynamics and real options concepts and methods to project teams.

When Options that are "In the Money" Do not add Value

As described above, the option in the Project Isolated case had a net positive expected option value, signaling that the project managers should spend $500,000 to obtain the option because it will add project value. Options with positive value are said to be "in the money." However, not all options that are "in the money" add value. Whether an option *actually* adds value or not also depends on how uncertainties resolve (the forecasted equipment arrival date in this case) and managerial decisions (the application of the exercise decision rule) in the particular project in which the option is used. For example, in the Project Isolated case, if the option is purchased but the uncertainty resolves such that changing to an airlift strategy is not needed the project value is *reduced* by the cost of obtaining and keeping the option (left side of Figure 5). Similarly, uncertainty can resolve such that changing strategies (if possible) would *add* value even if the expected value of the option was negative, the option was "not in the money," and no option was purchased. In these cases the option valuation (including by the method used here) tells the manager to make what is known in hindsight to be the wrong decision. This is due to option values being based on expected (i.e. mean) values and not the value in a single set of circumstances. Individual projects almost never behave exactly like the expected case. Markedly different than the assumption of many reported transactions for financial options the managers of large development projects make decisions based on individual projects, not averages of many projects. This may partially explain the slow adoption of real options by practicing project managers. These managers may intuitively foresee circumstances in which they might be forced to explain an expense they authorized (to obtain an option) that clearly did not add project value because the option was not needed. Using expected values allows valuation with uncertain futures but also makes the value added by options that are "in the money" uncertain. This emphasizes the importance of building and using models that accurately describe the behavior of uncertain systems and practicing managers.

Options that are Free to Obtain and Retain

In the Project Isolated example the project team had to pay $500,000 to reserve the right to airlift the piece of equipment in the future. This cost represented the cost of design and manufacture changes required to enable the equipment to be airlifted and the capacity reservation cost required by the airlift company. In this case, without incurring this cost the Project Isolated team could not reserve the airlift option. However, in certain circumstances the right to reserve an option can be free. Suppose the design and manufacture of the equipment was such that it did not require modification to be airlifted and the airlift company required a two month advance capacity reservation but did not require an upfront payment for this reservation. In this case the purchase of the airlift option would be free even though the exercise cost of the option would remain unchanged.

Project managers prefer free options to those that must be purchased. However, discussions with real option practitioners within BP reveal a potential pitfall with free options. These managers appear to fall pray to the false belief that only things that are costly can be valuable. Since option costs can affect the financial performance of a project, project managers are more likely to recognize, focus on, and value relatively expensive options in their decisions about if the option should be purchased. In contrast, free options are often not recognized as options and the potential value added to the project by their flexibility may be overlooked. Thus, the value added to the project through increased flexibility would not be captured in the project NPV analysis. This could lead to project undervaluation and termination of a potentially profitable project.

Although the Project Flexibility team had a system dynamics background they did not enter into the project looking for a new arena to apply system dynamics. What the team found as the project progressed was that there were several areas in which system dynamics could improve the development of flexibility with BP projects. These potential improvements are next presented along with the potential use of systems dynamics to address some of the Georgetown Challenges.

How System Dynamics can Facilitate Real Options Use

Applying system dynamics to real options practice can address some of the five challenges outlined by Triantis in the "Georgetown Challenge." Thereby system dynamicists can increase the use of real options in a multitude of industries while also exposing system dynamics to new audiences. Toward that end we describe how system dynamics can be used to address three of the Georgetown Challenges; refining the models of perfection, modeling managerial behavior, and developing heuristics.

Refining the Models of Perfection: System dynamics is particularly able to realistically model many systems that use real options while relaxing common assumptions of perfection used by traditional real option models. These include, but are not limited to, system dynamics' modeling of delays which cause imperfect markets, the ability to explicitly model managerial goals and incentives that may vary from value maximization, and, as shown in the Project Isolated case, flexibility in generating and describing uncertainty.

Modeling Managerial Behavior: Modeling realistic managerial behavior in development projects is an area where system dynamics is well suited and has seen extensive application (e.g. Ford and Sterman 2003, Ford 2002, Sterman 2000, Joglekar and Ford 2005, Taylor et al. 2005). This capability can be used to develop models of managerial behavior when evaluating the purchase or exercise of a real option. The Reservoir Two case provides an example of the potential for system dynamics to improve the modeling of managerial behavior in a real options model. In addition to the basic decision rule for exercising the option, system dynamics can model other influences on managerial exercise choices, such as incentives, delays and biases, and nonlinearities. Also consider the option design process. The project manager for Reservoir Two realized that the initial project scope was not economically viable, given the reserve characteristics. Based upon this information the manager decided to utilize a more flexible approach to field development. Given more detail into the decision process, system dynamics could also be used to model the managerial decisions in this process. This model could then be used to forecast a manager's decisions given different circumstances and uncertainty evolution. This decision could then be compared to the optimal decision forecasted by a traditional real options model. Such research would provide real option researchers data on the validity of "perfect manager" assumptions.

Developing Heuristics: System dynamics's use of bounded rationality and simple algebraic equations to describe decision-making make it an excellent modeling approach for designing and testing option heuristics. Few simple system dynamics models have been used to value real options. (Cooke 2004). System dynamics can also add value to this area by modeling the effects of feedback on option value. The transparency of system dynamics and model analysis techniques available for system dynamics models can help identify and explain the drivers of option value (or lack of value).

Conclusions

The current work describes and discuses the application of system dynamics to further real options development and valuation using two cases from the oil and gas industry. Several fundamental system dynamic methodologies can be applied in the real options field including reference modes, model dominance analysis, causal loop diagrams, subsystem diagrams, and formal system dynamics modeling (Table 1). System dynamics can also be used as a tool to address several challenges currently facing the real options community, particularly refining the models of perfection, modeling managerial behavior, and developing heuristics. The use of systems dynamics in real options development and valuation can 1) help address several key challenges facing the real options community and increase the use of real options in industry 2) allow system dynamicists to increase value through developing and valuing flexibility and 3) open system dynamics to new markets of research collaboration and potential clients.

Future research can focus on the application of system dynamics to the Triantis Georgetown Challenges. Existing system dynamic project development models (e.g. Taylor et al. 2005, Repenning 2001) can be applied to value development options in manufacturing and construction. These models could be expanded to include real option valuation sectors utilizing Equation 2. A research area of particular interest to real option researchers is the validity of the value maximizing manager assumption when deciding whether to exercise an option. Models of managerial behavior could be developed that can test the validity of this assumption and, if necessary, develop improved theories.

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