Original Article

Real option perceptions among project managers

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Abstract Effective and efficient planning for and management of project risk requires the management of uncertainty. Real options can be an effective tool for managing uncertainty and thereby increasing project value. As most managers do not use real options, but instead intuitively manage uncertainty, understanding the similarities and differences between decision-maker perceptions of real options and real options theory is critical for improving the use of real options for risk management. In the current work, an experiment using a simple uncertain development project and a simulation model capture managers' perceptions of real options, including option values. Results show that subjects valued flexibility and conceptually understood option values in ways consistent with theory. Implications for real options research and development are discussed.

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Introduction

The uncertainty inherent in development projects makes it difficult to plan and manage to meet objectives. Unpredictable development environments, immature technologies and complex interfaces in integrated systems often generate performance that varies widely from project targets. Uncertainties can be primary causes of cost overruns, delays and substandard product performance. Effectively managing uncertainty can increase project value by reducing the likelihood of not meeting targets (risk management), by adding benefits beyond original targets (performance enhancement), or both. Risk management focuses on decreasing the possibility and magnitude of loss. Reducing losses increases project value. In contrast, performance enhancement focuses on increasing the possibility and magnitude of gain, which also increases project value.

Whether uncertainty management is viewed as a form of risk management or performance enhancement can depend primarily on the targets. For example, postponing equipment purchases can add value to the purchaser if future prices are uncertain and happen to fall. A lump sum contractor will likely perceive managing this uncertainty as risk management if the bid is close enough to costs that the value addition is required to ensure that costs do not exceed the bid. But the same lump sum contractor may perceive managing the same uncertainty as a means of boosting profits if the bid far exceeds costs. Researchers and some practitioners recognize the potential of managing uncertainty to improve performance beyond targets as well as for risk management (Amram and Howe, 2002; Ford *et al*, 2002; Ward and Chapman, 2003; Yeo and Qiu, 2003; Ng and Bjornsson, 2004). The same basic risk management theories and models can be applied, regardless of the levels of performance targets, to increase development project value through the management of uncertainty. Therefore an increase in project value can be a useful metric for either uncertainty management purpose.

Both the amount and nature of project uncertainty make it difficult to plan for and manage risk. Miller and Lessard's (2000) study of 60 large ($985 million average cost and 10.7 years average duration) engineering projects concluded that project success depended largely on the amount of uncertainty and how these uncertainties were managed. Ceylan and Ford (2002) investigated the complex nature of uncertainty in a single, large ($2.4 billion) Department of Energy research and development project and concluded, in part, that the complexity of managing uncertainty in practice currently exceeds the ability of available tools and methods. Proactively planning for and managing development project risk requires forecasting both performance under uncertainty and the impacts of potential decisions. Frequently a lack of data or understanding of historical experiences for prediction, long project durations and complex interactions between project components (including decisions) make this difficult. Managers of development projects need decision-making theories, methods and tools to use in planning for and managing risk to increase project value.

Courtney *et al* (1997) propose a framework of four levels of uncertainty and analytic tools suitable for each level (Table 1). Matching levels of uncertainty and decision models allows for better determination of the best strategy to use.

In Level One uncertainty, the future is sufficiently known such that project behaviors (for example, costs) can be reasonably estimated and valued.

Table 1: Four levels of uncertainty and tools (extracted from Courtney *et al* (1997, pp. 70–71))

Level of uncertainty	*Uncertainty description*	*Recommended tools*
1	A clear-enough future	'Traditional' strategy tool kit
2	Alternate futures	Decision analysis, option valuation models, game theory
3	A range of futures	Latent-demand research, technology forecasting, scenario planning
4	True ambiguity	Analogies and pattern recognition, nonlinear dynamic models

Examples of Level One uncertainties in development projects include delivery times of materials and weather. The analytic tools used result in single-point estimates of value. Brennan and Trigeorgis (2000) characterize these models as static and mechanistic. Discounted cash flow models, such as the Net Present Value, are one example of linear passive models often used with Level One uncertainties. Stand-alone risk assessment techniques such as sensitivity analysis and scenario analysis are used as well, but more to find key value drivers and the most likely outcome than to guide decision-making. Due, in part, to the difficulty of determining discount rates, Level One models are best used when project risk remains relatively constant and a single discount rate could be used.

Level Two uncertainty occurs when there are a few possible alternate outcomes. Examples of Level Two uncertainties in development projects include labor strikes and subcontractor bankruptcy. The outcomes are discrete; there may, or may not, be probabilities of the likelihood of occurrence; and the most effective strategy depends on the outcome eventually realized. Valuation models now need to be nonlinear. Brennan and Trigeorgis (2000) refer to such models as (partially) controlled cash flow models and dynamic, game-theoretic models.

Level Three and Four uncertainties are no longer mathematically 'defined'. Level Three is similar to Level Two but where there is a bounded continuum of possible outcomes (a bounded feasible region). An example of a Level Three uncertainty in a development project is the amount of oil in an underground reservoir. Level Four is where '… multiple dimensions of uncertainty interact to create an environment that is virtually impossible to predict' (Courtney *et al*, 1997, p. 70). Courtney *et al* (1997) suggest that nonlinear simulation models are used to analyze and manage these uncertainties.[1] Development projects rarely experience uncertainties to a degree that they are 'virtually impossible to predict' outside of a bounded feasible range. This is largely because developers will rarely risk the large resource commitments needed for development of projects with Level Four uncertainty.

Development projects often experience multiple dimensions of uncertainty that interact and create highly challenging managerial circumstances. Many generate sets of discrete possible outcomes that require flexibility and cannot be effectively and efficiently managed with tools for Level One risks (Dixit and Pindyck, 1994; Copeland and Antikarov, 2001; Amram and Howe, 2002; Yeo and Qiu, 2003; Ng and Bjornsson, 2004). Therefore, the current work focuses on the management of Level Two 'alternate future' uncertainties. Bailey *et al* (2000) suggest decision trees and options as two primary tools for managing these types of risks. Miller and Lessard (2000), Ceylan and Ford (2002), and others have found the managerial flexibility that decision trees and options model to be a primary reason for the success or failure of projects.

Although decision tree analysis has many strengths and can be valuable in structuring uncertainty management (Howard and Matheson, 1989; Kemna, 1993; Shenoy, 1994; Teisberg, 1995), many researchers suggest that option models are the preferred decision-making framework. As with any discounted cash flow-based model, decision trees cannot properly model how decisions to delay, abandon, expand, contract or switch project components or processes impact project risk. Decision trees use a risky discount rate to reflect both time and risk preferences. But, unless economically adjusted, the rate does not properly reflect volatility when an option (asymmetric payoffs) is present (Trigeorgis, 1996; Lander, 1997; Lander and Pinches, 1998; Hevert, 2001; Triantis and Borison, 2001; Feinstein and Lander, 2002; Eapen, 2003; Garvin and Cheah, 2004; McDonald, 2006; Block, 2007). Furthermore, although the appropriate risk-adjusted discount rate for an option can be determined when the value of the option is already known (Hevert, 2001), there is no direct way to determine it when the value of the option is not known (Feinstein and Lander, 2002). These limitations are particularly relevant to the current work because of its focus on risk management when decision-makers can delay a critical decision.

Real options

Finance broadly defines an option as a contract that grants the option holder the right, but not the obligation, to purchase (call option) or sell (put option) the underlying asset on or by a certain date (expiration date) for a certain price (exercise price). Traditional market traded options and option pricing models are for options on financial assets (for example, shares of stock) and other market traded assets. Real options[2] differ from financial options in that the underlying assets are real assets that are often not traded and represent, for example, contingent decisions to delay, abandon, expand, contract or switch project components or methods. (See Lander (1997), Lander and Pinches (1998), and Trigeorgis (1993, 1996, 2005) for categorizations and descriptions.) Real options theory formalizes this form of flexibility in the central premise that, if future conditions are uncertain and changing the strategy later incurs substantial costs, then having flexible strategies and being able to delay making decisions until uncertainty (at least partially) resolves can have value when compared to making all strategic decisions now. Real options can provide opportunities to increase benefits (calls), limit losses or costs (puts), or both. When used to limit costs of development projects, such as in the current work, real options are a form of risk management.

Real options theory focuses on estimating the values of alternative strategies by identifying available future alternative actions and specifying, depending how uncertainty resolves, which choices among them should be made to maximize value. For example, by building an expandable manufacturing plant, an owner purchases a real option to increase the plant's capacity some time in the future if product demand increases and avoids expansion costs if product demand remains stable or decreases. The extra cost required to make the plant expandable is the price of the option and an indication of the minimum value of the option to the owner, whereas the cost of expanding plant capacity is the cost to exercise the expansion option.

Methods for pricing real options have been developed and analyzed (Quigg, 1993; Trigeorgis, 1993, 1995, 2005; Dixit and Pindyck, 1994; Kulatilaka, 1995; Teisberg, 1995; Lander, 1997; Lander and Pinches, 1998; Brealey and Myers, 2000; Borison, 2005; McDonald, 2006). Real option valuation models have been effectively used to demonstrate how real options can increase project value, including through engineering design (Baldwin and Clark, 2000; Park and Herath, 2000; Ford *et al*, 2002; Zhao and Tseng, 2003), testing and learning through pilot projects (Benaroch, 2001; Sadowsky, 2005), schedule control (Ford and Bhargav, 2006) and financing (Ho and Liu, 2002; Cheah and Garvin, 2008). Huchzermeier and Loch (2001) provide an example, modeling how and when managerial options to abandon, continue or improve a research and development project can add value in circumstances of uncertainty, including project budget, product performance and schedule. Their model includes the expected performance of the project's product, suggesting that the project manager's perceptions are important in fully understanding real options. Other research has demonstrated the application of real options, for example, to natural resources and land development, flexible manufacturing, research and development and innovation, mergers and acquisitions, leases, and the labor force. (See Lander (1997), Lander and Pinches (1998), and Trigeorgis (2005) for reviews of the real options application literature.) In summary, real options have been demonstrated to be capable of improving project risk management.

The critical role of managerial perceptions of real options

In addition to pricing managerial flexibility, real options have contextual meaning, capture strategic considerations, frame investments and decisions, facilitate communication among decision-makers, and guide implementation (Lander and Pinches, 1998; Amram and Kulatilaka, 1999; Triantis and Borison, 2001; Miller and Waller, 2003; Alessandri *et al*, 2004; Garvin and Cheah, 2004; Amram, 2005; Triantis, 2005; Baker *et al*, 2011). Therefore, real options can be used to expand the range of strategies considered, focus attention on objectives instead of solutions, evaluate sensitivity to multiple project futures, test plans, and increase awareness of the value of flexibility (see Ford *et al* (2004) for a review). These features of real options can improve risk management by helping decision-makers recognize, design and use flexible alternatives to manage uncertainty.

The critical project risk management functions described above highlight the role of the cognitive aspects of real options use. The research supports this. Researchers have found that managers are aware of uncertainty and that it can impact project performance (Cheah and Garvin, 2008; Duncan in Bowman and Hurry, 1993; Kellogg, 2010). Miller and Lessard (2000) concluded that managers *intuitively* manage uncertainty to add value. Eapen (2003), McCormack *et al* (2003), McDonald (2006), and Moel and Tufano (2002) agree that managers implicitly understand flexibility has value and use real option thinking. Cheah and Garvin (2008) say managers address uncertainty by intuitively incorporating flexibility and add that they do so by using feasibility studies, flexible designs and staged construction. Bowman and Hurry (1993) suggest small investments followed by larger investments facilitate experimentation and learning. Triantis and Borison (2001) claim that managers often consider how uncertainty will evolve and also understand their potential strategic choices, both of which are central to using flexibility to manage uncertainty. Ford (Paul Weber, 2001, personal communication) observed managers using flexibility in the development of a large US Department of Energy research and development facility, including the explicit identification and description of uncertainties and quantitative performance forecasting. Johnson *et al* (2006) describe cases of managers using flexibility in oil and gas development projects.

However, some researchers have identified cognitive barriers to real options use in projects. Real options theory is dynamically complex, with tightly linked components, delays and time-varying behavior. Previous research in human decision-making has demonstrated that people have difficulty predicting the behavior of dynamic systems and managing systems with long delays and uncertainty (Sterman, 2000). Barnett (2005) describes and supports the size and nature of the impacts that attentional constraints impose on the effective use of real options by managers. Those constraints may prevent managers from completely and optimally noticing potential options, selecting among potential options, and developing, maintaining and exercising the selected options. Ceylan and Ford (2002) conclude that, although managers understand that flexibility may be used for managing uncertainty, '… the practice is rarely structured into the frameworks developed by options theoreticians' (p. 250). Additionally, managers may not be familiar with the option valuation approach or comfortable with the mathematical complexity of the techniques (Lander and Pinches, 1998; Feinstein and Lander, 2002; Eapen, 2003; Triantis, 2005; Block, 2007; Matthews *et al*, 2007). Communication about options may be a barrier. For example, Lander (1997) shows that influence diagrams graphically represent the decision problem in a more descriptive and compact manner than do option pricing models and decision trees. Ford and Garvin (2009) identify, describe and support six barriers to real options use, including project manager risk perceptions, mathematical model complexity and project manager objectives, that may contribute to managers not using real options theory in practice.

The larger challenge addressed here is that, despite having been demonstrated to improve project value, and despite the frequent use of flexibility that can be structured as real options, real options theory is rarely used by practitioners (Lander and Pinches, 1998; Graham and Harvey, 2001; Huchzermeier and Loch, 2001; Triantis and Borison, 2001; Triantis, 2005; Coleman *et al*, 2010). Ryan and Ryan (2002) surveyed 205 Fortune 1000 Chief Finance Officers and found that only 11.4 per cent use real options, while 96 per cent use Net Present Value. Block (2007) found only slight improvement (to 14.3 per cent) in the following five years. Baker *et al* (2011) surveyed Canadian firms, finding that only 16.8 per cent reported using real options. Which, if any, cognitive barriers suggested by the literature impede real option use? The answer is important. If risk managers lack fundamental knowledge about and understanding of real options concepts and relationships, then basic education about real options is a required next step in improving risk management with real options. But, if, as some researchers have claimed, risk managers have a fundamental understanding of real options, improving practice with real options requires a different focus, perhaps on the development of *user-friendly* (Feinstein and Lander, 2002; Triantis, 2005) application tools and methods. Therefore, understanding how decision-makers in general and project managers in specific use real options to respond to uncertainty in their risk management decision-making and how they perceive and value flexibility is important for improving risk management practices. Measuring, describing and understanding how decision-makers perceive real options is a critical first step.

Although previous real options research has used isolated anecdotal settings, none objectively gathers and describes the perceptions of real options in controlled conditions. The current work collected and describes real options perceptions in controlled risk management experiments, thereby addressing how decision-makers manage risk in development projects, improving the understanding of the interdisciplinary nature of risk management, and contributing to the evolution of risk management approaches. In contrast to the dominant strategic and valuation perspectives of real options, the current work focuses on the decision-making aspects of using real options for risk management and reveals new information on decision-makers' understanding of real options. The current work contributes new data and analysis of decision-maker perspectives of project management real options, including valuation.

The remainder of the article is structured as follows. The next section describes the research methodology and design used to elicit and describe perceptions of real options in simulated development projects. The specific experimental settings are then described, followed by how those settings use real options. The subject and experimental protocols are followed by results. The results are used to describe perceptions of real options in several forms. Conclusions and discussion of the implications for real options research and development are followed by suggestions for future research.

Research Methodology and Design

A simulated uncertain development project called the Rig Installation Challenge was designed, built and used to develop improved and objective descriptions of managerial responses to risk. Three types of decisions based on the amount of managerial flexibility provided are possible in the Rig Installation Challenge: no decision, an uninformed decision and an informed decision. The first version includes uncertainty but no decisions because no flexibility is provided. The uninformed version includes the same uncertainty as the no decision version but provides a choice that impacts performance. It is called uninformed because the subject does not know the information required to make the least-cost choice when the decision must be made. The informed version includes the same uncertainty and same choice, but also an opportunity to delay deciding until the uncertainty is resolved, thereby allowing an informed choice. Each of these versions is described further below. Research subjects managed this uncertain project first with uninformed and then with informed risk management decisions being available. In both decision-making modes, subjects had repeated opportunities to purchase a means of avoiding an expensive system integration. To collect multiple types of data, subjects were interviewed twice, once after managing the project in the uninformed decision-making mode and then again after managing the project in the informed decision-making mode. Responses to interview questions revealed how subjects made decisions and perceived and valued flexibility for risk management and their perspectives on other issues related to flexibility. A system dynamics simulation model (Sterman, 2000) of the experimental project and subject decision-making was also developed to help assess the results (Appendix). This allowed for simulating the management of many projects under a wide range of conditions and policies. The results were evaluated using data collected from the experiments, subjects' answers to interview questions and simulation results.

The Basic Rig Installation Challenge

The Basic Rig Installation Challenge (the Basic Project) was used to model risk management with no flexibility/no decisions and with uninformed decisions. The project represents the installation of a deep-water exploration and production rig for oil and gas in the Gulf of Mexico. A rig is composed of multiple systems such as the sea floor anchors, support cables, flotation can, topsides, drill rig, and so on. The project simplifies the complexity of rig installation and system integration into 16 generic interacting systems that must be arranged as shown on the right side of Figure 1 to complete rig installation. Systems are represented by playing cards numbered 1–16. The systems (cards) typically move one position (squares in Figure 1) to the right each week (each draw of a new card). All systems start in fabrication (left side of Figure 1) in a random and unknown sequence (the 16 cards are shuffled and face down). Systems are assumed to have been built in different yards by different contractors and leave fabrication in a random and unknown sequence at a rate of one system per week. Each system is transported over two weeks (2 further draws of new cards) to the dock (square at fork in paths) and then to the project site (right side of Figure 1) through one of three paths.

In the no-flexibility/no-decisions version of the Basic Challenge, all systems are sent directly to the site for installation. Only this action is allowed, therefore no decisions are required. If the system meets the interface constraints,[3] the system is successfully installed at the site (middle path in Figure 1). Successful installation costs $10 000 per system installed. A failed installation attempt (interface constraints are not met) means the system must be redesigned and rebuilt before installation (bottom path in Figure 1) and costs $40 000.

In the uninformed version of the Basic Challenge, subjects have a choice between two alternate actions. They can choose to send each system directly to the site for installation or, instead, to the testing yard. Sending a system to install has the same consequences as in the no-flexibility/no-decisions version

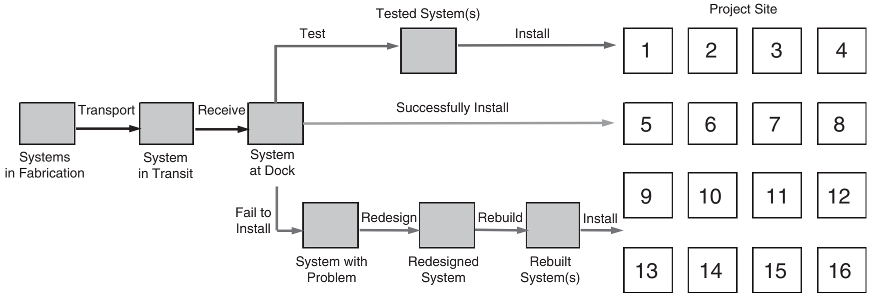

Figure 1: Operations in the rig installation project.

described above. Testing a system before installation (the upper path in Figure 1) costs $20 000 but assures successful installation by holding systems until interface constraints are met. Before each system leaves fabrication and before the system number is known, subjects choose between sending the system directly to the site and trying to install it without testing (decide To-Site) and reserving the yard to test the system (decide To-Yard). Systems arrive at the dock two weeks after leaving fabrication, where the system number is revealed (card is turned face up), the To-Site/To-Yard choice made when the system left fabrication is implemented, and the result (successful installation/rework required or to testing yard) completed.

Uncertainty is introduced into the Basic Rig Installation Challenge through the random order of systems leaving fabrication. Risk is introduced through the potential for increased cost due to rework. In the uninformed version, limited managerial flexibility is introduced through the choice of alternate actions (To-Site/To-Yard) made for each system. The To-Site/To-Yard decision is difficult because the choice to test that prevents expensive rework costs more ($10 000 more per system) than sending the system directly to the site and subjects must make the To-Site/To-Yard choice before the system number, and therefore the availability of a shared system interface, is revealed (that is, subjects are uninformed about the system and if it will successfully install). It is also a difficult decision because the conditions that determine whether installation will succeed or fail evolve between the time of the decision (at fabrication) and the time (two weeks later) when the uncertainty is resolved (at the dock).

The Advanced Rig Installation Challenge

The cover story, systems, movement of systems and unit costs for the three installation paths in the Advanced Rig Installation Challenge (the Advanced Project) are the same as in the Basic Project. The only difference is that the Advanced Project allows subjects to make a different decision in order to manage project risk. In the Basic Project with uninformed decision-making, there is no opportunity to delay choosing whether to send a system directly to the site or to the testing yard, meaning there is no opportunity for uncertainty to resolve to any degree before having to decide how to proceed. In contrast, in the Advanced Project, managerial flexibility is provided by allowing subjects to choose to delay decisions about whether to send systems directly to the site or to the testing yard until the systems reach the dock and their numbers are revealed. This allows subjects to make a To-Site/To-Yard choice when they know whether or not the system meets the interface constraints. Delaying decisions allows a subject to avoid an expensive installation due to rework by testing systems that would fail installation if sent directly to the site.[4] If this opportunity were free, all rational subjects would choose it for every system that would benefit from the decision-maker knowing the system number. Therefore, in the Advanced Project, delaying the decision about a system incurs an additional cost. Subjects are offered an opportunity to purchase a right to delay their decision for each system at a price set by the experimenter. Prices were adjusted to identify each subject's perceived value of the flexibility, as reflected in the maximum price the subject was willing to pay for the right to decide later. The price started at $2000 and was increased by $1000 for the next system's delay if the subject accepted delaying the current system decision and was decreased by $1000 if the subject declined to purchase the delay of the current system, with a minimum of $0. See Wu (2005) for additional details on experiment design and operation.

As with the Basic Rig Installation Challenge, uncertainty is introduced into the Advanced Rig Installation Challenge through the random order of systems leaving fabrication. Risk is introduced through (i) the potential for increased cost due to rework if the right to delay a decision is not purchased and the high-cost To-Site/To-Yard decision is made at fabrication and (ii) the potential to pay more to delay a decision than is saved by delaying the decision. Managerial flexibility is introduced through the Delay/Decide-Now choice made for each system at fabrication. The Delay/Decide-Now decision is difficult because the potential savings varies (for example, the first and last two systems always install successfully and so delaying is not cost effective) and the cost to delay varies. Estimating the potential savings and costs for comparison is difficult due to system uncertainty and bounded rationality. It is also a difficult decision because the conditions that determine whether delaying reduces costs evolve during the project as the 16 systems are fabricated and transported to the dock.

Risk Management and Real Options in the Rig Installation Challenge

Subjects use flexibility to manage the risk of a high installation cost in the Rig Installation Challenge. As described above, three levels of managerial flexibility are possible: no flexibility (only one choice of action), uninformed decision-making (choice of alternate actions without knowing the system number) and informed decision-making (can delay choosing an action until the system number is known). As the nature and amount of the uncertainty is the same for each form of flexibility and each is affected by the interaction of the project conditions and subject decisions, the risk management performance in the Rig Installation Challenge is the result of the decision strategy used by each subject.

With no managerial flexibility, the subject watches as uncertainty resolves, takes no action and accepts the resulting outcome. Two rigid policies were used to describe risk management in the Basic Project: an extreme risk-seeking policy and an extreme risk-averse policy. The extreme *risk-seeking* policy sends every system directly to the site to attempt installation. Although this policy provides the only opportunity for the minimum cost, it also incurs the risk of very high costs. Costs using the extreme risk-seeking policy depend only on the system sequence (uncertainty). The minimum cost of \$160 000 occurs if all systems meet the interface requirements (16 × \$10 000). The maximum cost of \$550 000 occurs when the maximum number of systems require rework ((1 × \$10 000) + (13 × \$40 000) + (2 × \$10 000)).[5] The extreme *risk-averse* policy sends all systems after the first one to the yard for testing,[6] avoiding any chance of the expensive rework. This policy incurs a project installation cost of \$310 000 ((1 × \$10 000) + (15 × \$20 000)) regardless of the system sequence.

With the uninformed form of risk management, subjects choose between sending each system directly to the site to attempt installation or to the testing yard. Choosing between these actions gives mangers a limited way of responding to their perceptions of installation risks (rework) and protection from additional costs (by testing). Costs in this version of the Rig Challenge depend on the system sequence (uncertainty), the risk manger's perception of the risk of unsuccessful installation, the added cost of protection (\$10 000 per system) and the risk preference of the subject. The minimum and maximum costs in the uninformed version are the same as in the no-flexibility/no-decisions version because both extreme policies are available to subjects.

With informed decision-making, subjects make two decisions, whether or not to make the To-Site/To-Yard decision before the system leaves fabrication or to pay more to delay that decision and the To-Site/To-Yard decision. When choosing to delay a decision, a subject purchases a real option that provides an opportunity (but not the obligation) to switch from a To-Site decision to a To-Yard decision after the uncertainty about the system number has been resolved. Costs in this version of the Rig Challenge depend on the system sequence (uncertainty), the subject's perceptions of the installation risk, the risk preference of the subject (reflected in both the To-Site/To-Yard decision and the use of the real option to delay that decision), and the cost of the real option.

Research Subjects and Experiment Protocol

The target population is practicing project managers. However, differences in education, training and professional experience in managing risk vary widely across practicing managers and may disguise perceptions of real options. To partially control for these factors and due to subject availability, time and resource constraints, civil engineering graduate students were chosen as the subjects. The straightforward nature and transparency of most of the Rig Installation Challenge and clarity of the decision-making tasks suggest that differences in technical knowledge or experience between practitioners and students will not impact results (students and project managers were assumed to have the same level of knowledge necessary to manage the Rig Installation Challenge). Students and managers are expected to perform similarly on information processing tasks such as the tasks in this experiment (Khera and Benson, 1970;

Ashton and Kramer, 1980; Singh, 1998). If the perceptions of civil engineering graduate students are consistent with intuitive real options risk management for increasing project value, then support for practitioners would likely be stronger due to them having equal or more education, training or experience.

Subjects sought to minimize total installation costs. Motivation for good performance was provided with $10 compensation to each subject for participation and monetary prizes ($50, $25, $15, $10, $10, $10) for the top six performers. Each subject managed one uninformed Basic Project to become familiar with the project and experiment processes and how performance was measured. Subjects then managed two more Basic Projects using their best strategies to achieve the lowest total installation cost. The experimenter verbally guided subjects through each project to ensure compliance with experimental protocol but did not provide advice on decision-making. Project conditions, costs and subject decisions for each system were collected each simulated week by the experimenter and stored in an electronic data base. A semi-structured interview to explore how subjects made decisions was performed after the two Basic Projects. Subjects were then instructed concerning the use of flexibility in the Advanced Rig Installation Challenge. Three to six Advanced Projects were managed by each subject. A second semi-structured interview performed after the Advanced Projects emphasized differences between the Basic and Advanced Projects. Lastly, a computer model (see Appendix) was used to simulate some risk management conditions and policies that were not available or reasonable (for example, because no decisions were required) through experiments with human subjects.

Results

Data from 125 projects (42 Basic Projects with uninformed flexibility and 83 Advanced Projects with informed flexibility) managed by 21 subjects were collected. Subjects spent an average of two hours (total) on the experiment. One Advanced Project was deleted from the results because of the subject's misunderstanding of flexibility. The computer simulation model of the Basic Project was used to generate the costs of projects across a range of risk preference policies. In the Basic Project, subjects usually started with To-Yard decisions and increasingly chose To-Site as the project evolved. Therefore, these policies were described with the maximum number of unknown systems that could fail before switching from a To-Yard decision to a To-Site decision. For example, the extreme risk-seeking policy is described with a value of 13 because if 13 or fewer systems could fail (the first and last two systems cannot fail to install) the policy sends the next system to the site. Simulations of projects with 200 random system sequences were run for each of the 14 policies (0–13 systems could fail). The average costs for each policy were used to identify the near optimal[7] policy by identifying the policy with the best performance (lowest average cost). The near optimal policy in the Basic Project is to switch from deciding To-Yard to deciding To-Site when three unknown systems could fail.

The computer model of the Advanced Project was used to simulate projects across a range of real option purchase policies using the near optimal Basic Project policy when the real option was not purchased. The option purchase policies reflect the relative impacts of the two factors subjects said were used in deciding whether to purchase a right to delay deciding: the amount of uncertainty and the price of the right to delay (the option price). Interview data support that both matter. Subjects were asked:

> If you managed the Advanced Project again exactly as we just did *except* that systems that would share a corner with a previously installed system can be successfully installed as well as systems that would share an edge, would you delay your decisions more often?, Would you expect net savings to be the same, more, or less?, and Why?

Twenty of 21 subjects (95 per cent) believed that delaying decisions would be worth less because the suggested change would reduce uncertainty.

The simulated option purchase policies ranged from a complete dependence on uncertainty to a complete dependence on the price of the option. Simulations of projects with 200 random system sequences were run for policies from 100 per cent uncertainty impact/0 per cent cost impact to 0 per cent uncertainty impact/100 per cent cost impact in increments of 10 per cent. As before, the average costs for each policy were used to identify the near optimal real option purchase policy by identifying the policy with the best performance (lowest average cost). The near optimal option purchase policy is to base 90 per cent of the purchase decision on the level of uncertainty and 10 per cent on the relative price of the option. Risk management performance results are shown in Table 2.

Subjects in the Basic Challenge generated costs that were 7 per cent larger than those generated using the near optimal policy. Subjects in the Advanced Challenge generated costs that were 2 per cent larger than those generated using the near optimal policy. Providing limited managerial flexibility (Basic Project with uninformed decisions) improved project performance over the two rigid policies by 17 per cent (compared to the extreme risk-seeking policy) and 13 per cent (compared to the extreme risk-averse policy), adding to evidence that flexibility is a valuable risk management tool. Providing the real option to delay the To-Site/To-Yard decision improved subject performance 8 per cent compared to performance with limited flexibility and 24 per cent and 20 per cent over rigid policies (extreme risk-seeking and risk-averse, respectively), even though acquiring those options incurred additional costs. This last result expands the extensive existing evidence that real options can

Table 2: Rig installation challenge cost performance with different levels of flexibility

Flexibility provided	*Project type*	*Policy*	*N*	*Total cost ×($1000)*	*Cost compared to near optimal*	*Data source*
None	Basic Project (rigid)	Extreme risk-seeking (no decisions required)	200	326	29% > Basic 34% > Advanced	Simulated
None	Basic Project (rigid)	Extreme risk-averse (no decisions required)	1	310	23% > Basic 28% > Advanced	Calculated
Medium	Basic Project (alternatives)	Varies (subject specific)	42	270	7% > Basic 11% > Advanced	Student Subjects
Medium	Basic Project (alternatives)	Near optimal	200	253	4% > Advanced	Simulated
High	Advanced Project (options)	Varies (subject specific)	82	247	2% < Basic 2% > Advanced	Student Subjects
High	Advanced Project (options)	Near optimal	200	243	4% < Basic	Simulated

increase project value to include experimental evidence of decision-maker practices. F-tests showed that the variances of the uninformed and informed projects are not significantly different. Therefore, one-sided *t*-tests were used to test whether total costs of informed projects were less than total costs of uninformed projects. Informed project performance is significantly *better* than uninformed projects based on both an analysis of aggregate project performance ($P=0.0006$) or pair-wise subjects performance ($P=0.0002$).

Describing real option use in the Rig Installation Challenge

The results described above and other data collected through the experiments were used to objectively describe how subjects perceive real option values and uncertainty. Descriptions were developed using three types of data: subject's decisions during projects, subject interview data and simulation results. Exact values of the real options as perceived by subjects could not be captured directly using the experimental protocol. However, the envelope of values can be described with the data as follows. For each week of the Advanced Project, each subject either chose not to purchase the real option, thereby describing a maximum or *ceiling* value,[8] or chose to purchase the real option, thereby describing a minimum or *floor* value.[9] Perceived values for the subject must be between these ceiling and floor values. The ceiling and floor values of all Advanced Projects were averaged for each week of the project. The resulting values oscillate, largely due to the $1000 jumps in the offered price of the option when the offered price is near the perceived value and subjects purchase, then reject, then purchase the option. To partially compensate for this experimental-protocol-induced oscillation in the collected data, ceiling and floor values were the average of the data collected in each week and the data collected in the previous week.[10]

Answers to interview questions about the policies that subjects used also describe the shape of the perceived value of the real options over the project duration. Thirteen of 21 subjects (62 per cent) stated they would not purchase a right to delay deciding in the beginning or at the end of the project but would between these extremes. Purchasing options in the beginning of projects when the probability of failure was high was seen as unnecessarily adding cost because the system would most likely be tested anyway, so subjects knew to test the system without paying for the added information of knowing the system number. Similarly, purchasing options to delay near the end of projects when most systems had been installed and the probability of success was high was also seen as unnecessary because they could (relatively) safely send systems directly to the site without paying for the added information of knowing the system number. Subjects preferred paying to delay decisions in the middle of the project when it was difficult to predict the outcome of attempting to install the system directly (when outcome uncertainty was relatively high). The perceived ceiling and floor values of the real options are shown in

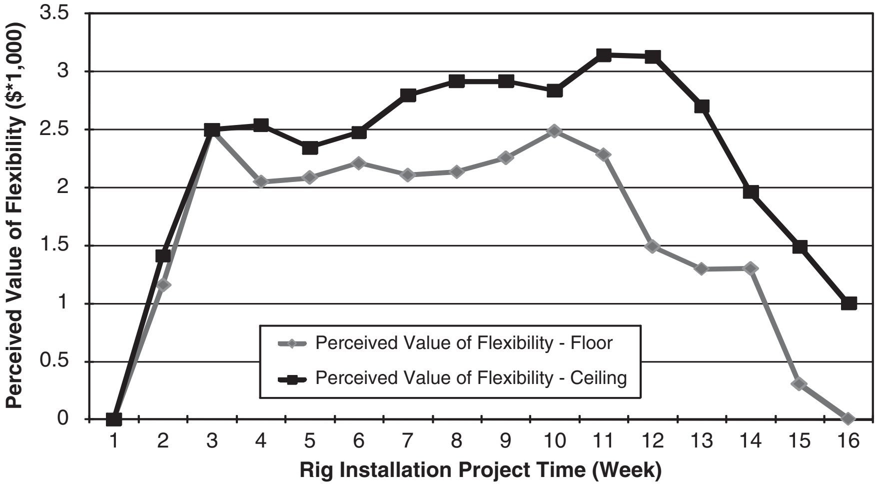

Figure 2: Envelope of perceived values of real options.

Figure 2. The shape of the envelope of perceived real options values is generally concave.

Subject perceptions of uncertainty could not be captured directly using the experimental protocol. However, their perceptions were incorporated into the computer simulation model based on interviews by formulating perceived uncertainty as the minimum of the likelihood of successful installation (thereby reducing perceived uncertainty early in projects) and the likelihood of unsuccessful installation (thereby reducing perceived uncertainty late in projects). The likelihood of installation success is dependent on both the system sequence and subject decisions made during a given project. Two extreme strategies were simulated to describe the envelope of possible perceived uncertainties,[11] each with the real option available. The extreme *risk-seeking* strategy was modeled by never purchasing an option and sending all systems directly to the site. The extreme *risk-averse* strategy was modeled by always purchasing an option and sending systems (i) directly to the site if they were sure to install successfully or (ii) to test if they would fail to install successfully. Two hundred projects with random system sequences were simulated for each extreme strategy and the perceived uncertainties for each policy averaged for each week to describe the perceived uncertainty envelope (Figure 3). The shape of the simulated perceived uncertainty over time is generally concave.

A comparison of Figures 2 and 3 shows that subjects valued flexibility and perceived uncertainty similarly (both curves are concave). This indicates that subjects perceive real option values as changing with uncertainty, and in a way that is consistent with a central tenet of real options theory.[12] This helps answer one of the questions posed above. The experimental results indicate that the subjects

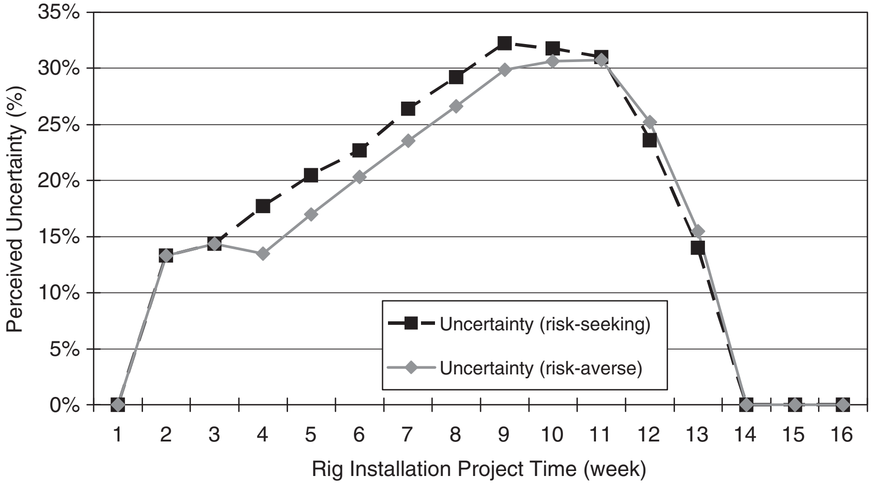

Figure 3: Perceived uncertainty versus Rig Installation Challenge time.

possess a fundamental knowledge about and understanding of real options concepts and relationships that is consistent with real options theory.

Conclusions and Discussion

Experiments in which human subjects managed a simplified installation portion of a development project and a computer simulation model were used to investigate the effectiveness of delaying decisions at additional cost on risk management performance. Experiments at three levels of flexibility were used to collect data on decisions and project costs. Risk management with limited flexibility improved performance over performance with no flexibility and risk management with real options generated the best project performance, even though acquiring the options added cost. Risk management decision-making was described with the perceived values of the real options over time and perceived uncertainties over time, which were similar and consistent with real options theory.

The results provide meaningful insight into the similarities between managerial perceptions and real options theory. A fundamental lesson from real options theory is that basic option values are a direct function of the amount of uncertainty being managed. The shared concave shape of subject perceptions of real option value (Figure 2) and uncertainty (Figure 3) indicates that subjects intuitively understood this fundamental real options relationship. To the extent that the results are also applicable to practitioners, they suggest that practicing risk managers also understand at least one of the fundamental drivers of option value and value options for risk management. This result partially contradicts the argument of some that decision-makers do not understand real options or how to use them and that this failure limits the application of real options. The improved total cost performance results when real options were used indicates that risk managers perceive flexibility in the form of an option as effective in managing development project risk and that managing uncertainty using real options increases project value (Table 2). This also supports a hypothesis that decision-makers have at least a conceptual understanding of the use and value of real options for risk management and suggests that understanding how real options work may be less of a barrier to their expanded use than other constraints such as tools, methods and conflicting objectives.

The conclusions are limited by the nature and scope of the research. Additional subjects could strengthen conclusions through additional data and analysis. Experimental conditions (for example, only one uncertainty) are significantly simpler than those experienced in practice, potentially allowing subjects to understand relationships more easily than is possible in practice. The subjects may not accurately reflect practicing risk managers. Future research can improve the confidence in the preliminary conclusions drawn here by expanding these experiments to address these limitations. Despite these limitations the results show that what is now needed to improve risk management practices further is not necessarily basic real options education but rather new and expanded application models and tools to use in planning for and managing risk. This implies that real options research should move beyond demonstrating that options can add value and develop user-friendly and effective tools and methods for applying real options theory to risk management practice.

The current work contributes to understanding and improving real options for risk management by: (i) collecting and describing real options perceptions in controlled risk management experiments, thereby providing a basis for an improved understanding of the interdisciplinary nature of risk management that is better than the use of only anecdotal or case study data, (ii) measuring a performance advantage experienced by decision-makers using real options when compared to rigid policies and more limited flexibility, and (iii) providing evidence that decision-makers conceptually understand, value and know how to use real options. This research also contributes to the development of real options as effective operational tools for risk management in development projects by identifying real options application issues as critical for improved real options use. Risk management tasks that might be improved include recognizing opportunities to exploit options, using options to structure the complex circumstances faced in practice, designing and evaluating strategies, and implementing chosen strategies. Initial steps in this direction (for example, Ford and Garvin, 2009 and Lander, 1997) should be extended.

Understanding similarities and differences between managerial perceptions of real options and real options theory is critical for developing operational real options theories that can improve risk management practice. Continued risk management and real options research that links theory to practice can increase the breadth and effectiveness of real options use to improve development project risk management.

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Notes

1 See Lyneis and Ford (2007) for a review of the application of system dynamics, one such simulation modeling approach, to development projects.
2 Myers (1977) is often credited with first modeling firm growth opportunities as call options and introducing 'real options' to finance theory.
3 The first system can always be installed successfully. Each system after the first system can only be installed when installation will create a shared system interface (card edge) with a previously installed system. For example, if only system 5 is installed, then only systems 1, 6 or 9 can be installed next.
4 Subjects in the Advanced Project could choose to send a system they know will require rework directly to the site even though they know it will increase costs above the decision of sending the system to be tested. However, this is never the rational choice and one that was not made by any subjects. Therefore, we assume perfect rationality in this case and that subjects make a decision to delay or not and, if not, To Site or To Yard.
5 The first and last two systems always install successfully.
6 This is not a rational policy because the last two systems will always install successfully and rational managers will send them directly to site, saving $20 000. However, the policy is a useful benchmark for evaluating other policies.
7 The policy and performance cannot be proven to be truly optimal using this method.
8 The maximum price subjects were willing to pay for an option may be less than (but not greater than) the price offered but declined. For example, a subject declining a $4000 offer to delay might also have declined a $3000 offer. Therefore the offered prices declined identify only an upper limit on the perceived values of the options, not exact perceived values of the options.
9 The maximum price subjects were willing to pay for an option may be more than (but not less than) the price offered and accepted. For example, a subject purchasing a $2000 offer to delay might also have purchased a $3000 offer. Therefore the offered prices accepted identify only a lower limit on the perceived values of the options, not exact perceived values of the options.
10 The experimental protocol limits the rate of decrease in the rejected price of the option to $1000 per week. Therefore the value ceiling and perceived values may also drop faster than reflected in weeks 11–16 in Figure 2.
11 No subjects used either extreme strategy consistently.
12 See Huchzermeier and Loch (2001) and Santiago and Vakili (2005) for exceptions.

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Appendix

Overview of Computer Simulation Model of the Rig Installation Challenge

The simulation model of the Rig Installation Challenge was developed using the system dynamics methodology (Sterman, 2000) that can reflect project processes, system uncertainty, subject strategies and perceived uncertainty. The model consists of three sectors: installation, strategy and cost (Figure A1). The installation sector exactly mimics the operations in the project managed by subjects. A random number generator simulates different sequences of systems arriving at the dock.

The strategy sector represents the policies that subjects used to make the To-Site/To-Yard decision and the Delay/Decide-Now decision for each system based on project conditions. With few exceptions, subjects described the likelihood of success or failure of an attempted installation as their basis for To-Site/To-Yard decision-making. In addition, most subjects described those likelihoods as being dependent on conditions that evolved in response to the uncertainty (system sequence) and management strategy (subject decisions). Therefore project conditions are passed from the installation sector to the strategy sector for use in decision-making.

The strategy sector compares perceived uncertainty to a threshold value that represents risk tolerance to make To-Site/To-Yard decisions. These decisions are passed to the installation sector for implementation in operations. In a similar manner, the strategy sector compares the unit cost of flexibility and perceived uncertainty to reflect option purchase decisions, which are passed to the installation sector. As described above and shown in the figure, option purchase decisions impact the future unit cost of flexibility, which impacts future option purchase decisions and costs.

Operations and purchases of real options are passed to the cost sector for use in calculating project costs and thereby measuring performance. The cost

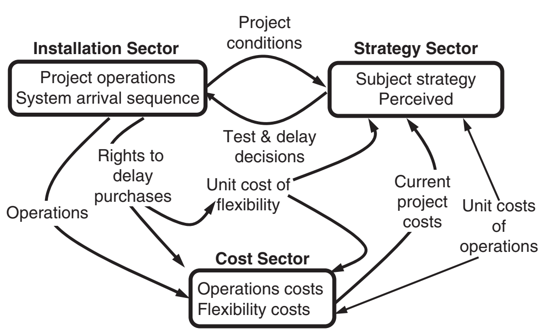

Figure A1: The Rig Installation Challenge: computer simulation model.

subsystem receives information on operations from the installation sector, applies the unit cost of operations and flexibility, and sums operation costs (testing, installation, rework costs) and option costs each week. Total project costs are the sum of the weekly costs over the project duration. See Wu (2005) for details of the simulation model.