MANAGERIAL PERCEPTIONS

OF OPERATIONAL FLEXIBILITY

A Thesis

by

YANZHEN WU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2005

Major Subject: Civil Engineering

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Approved as to style and content by:

David N. Ford (Chair of Committee)	Stuart D. Anderson (Member)
Thomas Wehrly (Member)	David Rosowsky (Head of Department)

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ABSTRACT

Managerial Perceptions
of Operational Flexibility. (May 2005)
Yanzhen Wu, B.S., Zhejiang University of Technology, China
Chair of Advisory Committee: Dr. David N. Ford

Large complex construction projects such as building an interstate highway, a dam, a chemical plant, an off-shore oil rig and a waste-to-energy plant often include unpredictable geological conditions, labor supplies, material deliveries, and weather that cause uncertainty. Effective and efficient acquisition and construction require the proactive management of these and other uncertainties to meet performance, schedule, and cost targets. Flexibility in the form of real options can be an effective tool for managing uncertainty and thereby adding value to construction projects. But flexibility can be expensive to obtain, maintain, and implement. Real options theory suggests a general approach and has developed precise valuation models. But these models of simplified real options (compared to managerial practice) have failed to significantly improve practice, partially because of a lack of knowledge of real options use by practicing managers. In contrast, the majority of managerial real options applications are identified, designed, valued, and implemented tacitly by construction managers. Understanding current practice and its similarities and differences with theory is critical for developing operational real options theories that can improve construction practice. Few descriptions of managerial real options practice exist as a basis for improvement.

To address this need the current research has experiment subjects manage a simple but uncertain installation project with managerial flexibility. Subjects repeatedly value an option to avoid a slow and expensive system integration failure. Real options theory is used to explain their behaviors by customizing the model of uncertainty to reflect the management context.

To further analyze managerial real options practice, a system dynamics simulation model of the experimental installation project is developed. Policies for using flexibility to manage uncertainty that are applied by subjects are modeled and performances are simulated across a range of uncertain conditions to evaluate and compare policy effectiveness.

All 21 subjects that participated in the research perceived flexibility as an effective tool in managing uncertain projects. But they are not aware of the factors that impact flexibility value. They correctly identified the relationship of some factors with flexibility value but not all of them and not the magnitude of impaction. Further research and development needs for expanding real options theory into the operational management of construction are discussed based on experiment and simulation results.

DEDICATION

To my family

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

1. INTRODUCTION

Large complex construction projects such as building an interstate highway, a dam, a chemical plant, an off-shore oil rig and a waste-to-energy plant often include unpredictable geological conditions, labor supplies, material deliveries, and weather that cause uncertainty.

Uncertainty is classified as three types according to Reinschmidt (2004): aleatory, epistemic, and volitional uncertainty. Aleatory uncertainty is objective and is the variability in repeated experiments. Epistemic uncertainty is subjective and exists because of our limited knowledge about reality. However, volitional uncertainty is not objective or 'out there', "but is capable of being manipulated by the very people who use them (uncertainty)." (Reinschmidt, 2004). For example, weather uncertainty is aleatory uncertainty, which is out of people's control. Geological condition is epistemic uncertainty, which exists because of our limited knowledge or lack of tools to know the reality beyond the surface of the ground. Uncertainty of the duration of activities such as design, procurement, and construction is volitional uncertainty, since managers modify their behavior based on their perception of the probabilities of different outcomes and thereby change those probabilities. For example, managers may hire more labors and have two shifts everyday instead of one shift if they perceive delay is likely.

Uncertainties can result in quality declines, cost overruns, and delays. However, uncertainties may increase project value if proactive management is used (Ford et al.., 2002; Ng and Bjornsson, 2003; Reinschmidt, 2004). For example, Ford et al. (2002) stated: "Delaying procurement, such as postponing equipment purchases, can add value to the purchaser if future prices are uncertain and happen to fall."

Uncertainty is expected to be bad in traditional project evaluation methods such as Net Present Value (NPV). NPV is a traditional project valuation method that uses the

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This thesis follows the style and format of the *Construction Management and Economics.*

discounted cash flow methodology. It is the difference between discounted net future cash flow expected from investment and the discounted initial investment. The discounted rate used in NPV is the firm's cost of capital or the minimum attractive rate, which implies a higher risk-adjusted discount rate (risk-free rate plus a risk premium) (Yeo and Qiu, 2002). The discounted rate used in NPV reflects managers' pessimistic attitudes to uncertainty and underestimates the upside value of uncertainty (Amram and Howe, 2002; Ng and Bjornsson, 2003; Yeo and Qiu, 2002). Not accounting the upside potential value of uncertainty after decision making is the biggest disadvantage of NPV, but it is widely used because it is easy to understand and calculate (Amram and Howe, 2002; Schmidt, 2003; Yeo and Qiu, 2002).

Researchers and managers are increasingly recognizing the positive value of uncertainty (Amram and Howe, 2002, Yeo and qiu, 2002). Effective and efficient acquisition and construction require the proactive management of uncertainties to meet performance, schedule, and cost targets. Another traditional project evaluation method, Decision Tree Analysis (DTA), considers uncertainty by listing all the possible results if uncertainty and different strategies are involved. However, DTA can only present a limited number of scenarios and it is static without capturing the value of flexibility (Lander and Pinches, 1998; Schmidt, 2003).

Real options theory makes up the disadvantages of NPV and DTA by capturing the value of flexibility. Real options is the extension of financial options to real assets (Amram and How, 2002; Ng and Bjornsson, 2003). An option is the right but not the obligation to take specific future action depending on future conditions, at some cost (Amram and How, 2002; Ford et al., 2002; Ng and Bjornsson, 2003). The cost of an option depends on six factors such as the uncertainty involved. This is explained in detail in the Literature Review section. For example, building an expandable waste-to-energy plant provides the opportunity to expand the plant in the future if industry waste dramatically increases. If the waste production remains stable or decreases, the cost of expansion can be avoided. The extra cost required to build an expandable plant, as opposed to a fixed capacity plant, is identified as the cost of the real option (flexibility).

Real options capture the value of managerial flexibility to address uncertainty in decision making (Amram and Kulatilaka, 1999; Ford et al., 2004; Yeo and Qiu, 2002). The value of managerial flexibility then can be used to calculate the total project value to help decision making. Real options could be growth options, deferral options or abandonment options (Ng and Bjornsson, 2003; Lander and Pinches, 1998). Real options theory does not suggest which the best strategy is, but it does provide space for managers to learn more about the project and to defer the decision to a later time when more information is collected and a final go or no-go decision can be made.

Flexibility in the form of real options can be an effective tool for managing uncertainty and thereby add value to projects. But flexibility can be expensive to obtain, maintain, and implement (Ford and Sobek, 2005). Therefore, which options (if any) to develop and use is not obvious. Option design and the assessment of the value are critical for effective option use.

Current construction managers focus on limiting project losses or mitigating risk in projects with high uncertainty (Ford et al., 2002; Reinschmidt, 2004). Risk avoidance, reduction, shifting, and transfer to mitigate risk are the general methods used in current construction practice (Ford et al., 2002). Real options theory is gaining interest among researchers and construction managers. Grenadier (1996) using the real options theory analyzed the influence of timing in real estate development (Grenadier, 1996). More areas and articles about real option application and models are provided in the Problem Description and Research Questions section. The potential of real option to improve construction management raises important questions: **How can construction managers access real options and use it to manage uncertain projects? How can construction managers use real options theory to create optimal policies to meet performance, schedule and cost targets?**

2. PROBLEM DESCRIPTION AND RESEARCH QUESTIONS

Real options theory suggests a general approach and has allowed the development of precise valuation models to capture the value of uncertainty and flexibility (Amram and Kulatilaka, 1999; Grenadier, 1996; Yeo and Qiu, 2002). However, real options theory is not as widely used as expected in the book *Real options: a Practitioner's Guide* written by Tom Copeland and Vladimir Antikarov. According to a Brain & Co. survey in 2002, only 11.4 percent among 205 Fortune 1,000 CFOs (Chief Finance Officer) use real options, while Net Present Value (NPV) topped the list at 96 percent usage (Teach, 2003). Lack of knowledge about real options by practicing managers and the easy application of traditional valuation tools compared with the sophisticated mathematical formulas of real options are the reasons for the low application of real options theory (Schmidt, 2003; Lander and Pinches, 1998; Teach, 2003).

In contrast, the majority of managerial flexibility is identified, designed, valued, and implemented tacitly by managers (Ford et al., 2002; Ng and Bjornsson, 2003). "Discounted cash flow is going to look at an average scenario, but if you talk to any manager, that's not how they think. They think about contingencies--- what's going to happen, how would we react. And even if they don't think that way, once it's presented to them that way, they say, 'Yeah, that's the way we should be thinking.'" comments Triantis, University of Maryland (Quoted from CFO magazine, July 01, 2003).

Lander and Pinches (1998) summarized real options application areas. Natural resources industries, such as the oil industry, are the initial areas to apply the real options concept. Other areas include competition and corporate strategies, manufacturing, real estate, and other areas (Lander and Finches, 1998). Examples of successful real options practice can be found in Keith and Max (1997), which described how British Petroleum (BP) and PowerGen, two United Kingdom companies, maximize the uncertainty value by applying the real options theory and achieved great success (Keith and Max, 1997).

Lander and Pinches (1998) classified real options as options to defer, options to abandon, growth options and more. He also reviewed the theoretical work of how to model and value all these types of real options and related decision strategies. For example, McGrath and Macmillan (2000) use real options theory to evaluate investment opportunities in high technology projects (Ng and Bjornsson, 2003). However, all the models and theories are not widely used by managers. Three challenging issues that are pointed out by Lander help explain why these models are not widely accepted: 1) these types of models of real options are not widely known and understood by managers; 2) the assumptions required to build the models conflict with practical real options application; 3) the assumptions in the models limit the scope of application (Lander and Pinches 1998).

According to Ford et al. 2002, "Construction managers are aware of potential benefits of uncertainty in projects. For example, experienced contractors with lump sum fixed project incomes understand that uncertainty in future prices may increase profits if prices fall or generate losses if prices rise." However, Miller and Lessard (2000) drew the conclusion from 60 large engineering projects studied that managers *intuitively* manage uncertainty to gain the upside value (Miller and Lessard, 2000). There is no clear managerial practice and real options framework for analysis, comparison, improvement, and wide application (Ford et al., 2002; Miller and Lessard, 2000). Ford et al. (2002) pointed out that one reason for difficulty in using a structured approach to address uncertainty is "it is difficult to access the values of flexible strategies when relatively large uncertainties exist."

Miller and Lessard (2000) suggested building a real options framework in large engineering projects but provided no detailed description of how to develop it. Ford et al. (2002) demonstrated the potential benefits of using real options in construction industries and identified the challenges of implementation but no further solutions were recommended.

In summary, there is a gap between current construction management practices and real options theory and models. Understanding similarities and differences between these two is critical for developing operational real options theories that can improve construction management practice. However, few descriptions of managerial real options practice exist as a basis for improvement. To address this problem, this research develops a simple but uncertain project to investigate how people perceive and value flexibility in practice.

This research focuses on the following **research questions**:

- How do people perceive and value flexibility in uncertain projects?
- What are the similarities and differences between people's perceived value of flexibility and value assessed with real options theory?
- How can the evaluation and use of real options by managers be improved?

3. HYPOTHESES

Five hypotheses from two perspectives are developed to help address research problems. Hypothesis 1 and hypothesis 3 are developed based on a managerial practice perspective. Hypothesis 2, hypothesis 4, and hypothesis 5 are developed based on real options theory pricing formula about flexibility value factors.

Real options theory is the extension of the financial option theory to real assets introduced by Massachusetts Institute of Technology (MIT) professor Stewart C. Myer in 1977 (Teach, 2003). Real options pricing models use a similar principle as financial option pricing formula. Financial option pricing formula is often estimated by using the Black-Scholes equation, which values flexibility based on six factors: stock price(s), exercise price(x), risk free rate of return(r), time to expiration (t), variance of returns on stock (σ), and dividends (δ). Some research points out that the main difference between real options and financial options is that the former option is applied to real assets which are tangible (Yeo and Qiu, 2002). The six factors in financial option can find corresponding elements in real options theory, as shown in Table 1 (Yeo and Qiu, 2002). The relations to value of flexibility of each factor are shown in Table 1 column 'Relation to Value of Flexibility'. Plus means positive correlated, minus means negative correlated. Three factors' (Asset value (s), Expiration time and Uncertainty) relationships with value of flexibility are built into Hypothesis 5, hypothesis 4 and hypothesis 2 separately.

Table 1 Six Factors of Value of Flexibility Pricing Theory

Variable	Relation to Value of Flexibility	Financial Options	Real options
s	+	Stock price	Present value of expected cash flows (Asset value)
x	-	Exercise price	Present value of initial project investment
r	+	Risk free rate of return	
t	+	Expiration time	
σ	+	Variance of returns on stock	Uncertainty of expected cash flows
δ	-	Dividends	Value lost over duration of option

Note: According to the Black-Scholes equation.

Hypothesis 1: Project managers value flexibility as an effective tool for managing uncertain projects.

According to majority literature about real options theory, real options theory is a good method to capture the value of flexibility. It is a good tool and should be built into strategic decisions. (Ford et al., 2002; Yeo and Qiu, 2002). Ford et al. (2002) said "…the explicit incorporation and valuation of options in construction project planning can help correct project *undervaluation* …" Yeo (2002) said "The real options approach in investment project evaluation appreciates the value of managerial flexibility and the potential of achieving improved returns on investment." Identified above in the Problem Description section, real option is not as widely used as expected. Why? Hypothesis 1 will test project manager's perception of flexibility. Do they think it is an effective tool for managing uncertain projects without considering the complex concept of real option and the mysterious equations? A more specific discussion of how this research tested this hypothesis is found in the Research Design section.

Hypothesis 2: Project manager's perceived value of flexibility is positively correlated with perceived uncertainty.

Uncertainty is the main factor influencing the value of flexibility (Amram et al., 1999). Amram stated: "When uncertainty is large, then it is more likely that the project value will wander into the flexible strategy regions." Increased uncertainty can increase the value of flexibility, which is also the main difference from traditional NPV analysis. In traditional NPV analysis, uncertainty reflects only risk and therefore has a negative impact. On the other side, as Ng and Bjornsson (2003) clarified "the value of an option lies in the asymmetry of the right to capture the upside without the obligation to bear the downside." For example, "a contractor who has the option to expand the highway from two lanes to four will not do so unless the increased revenue from tolls more than covers the construction costs." from Ng and Bjornsson (2003). Therefore, more uncertainty, which means a larger variance, will increase the value of flexibility (Yeo and Qiu, 2002). This research focuses on the relationship between uncertainty and the value of flexibility as perceived by managers.

Hypothesis 2 tests if the perceived relationship in construction manager's minds is consistent with the real options theory. Support for Hypothesis 2 can be indicated by a positive slope of an uncertainty versus perceived value of flexibility graph. A more specific discussion of how uncertainty was considered in this research and its relationship with perceived value of flexibility is found in the Research Design section.

Hypothesis 3: Differences in levels of risk-aversion impact the perceived value of flexibility.

Real options theory states that the value of flexibility is driven by six factors as described in the Literature Review section. Ng and Bjornsson (2003) mentioned the weak point in real options theory that "it ignores the decision maker's risk preference." Hypothesis 3 is designed to test if levels of risk-aversion impact construction managers' perceived value of flexibility. In our research, risk is defined as the degree of probability of certain loss or gain (Merriam Webster Dictionary). Risk-averse people try to avoid uncertainty or take the uncertainty when adequately compensated. Risk-seeking people prefer greater uncertainty than risk-aversion people. Support for Hypothesis 3 can be indicated by differences in perceived values of flexibility between managers who are risk-seeking and risk-averse.

Hypothesis 4: Value of flexibility in project manager's perception is positively correlated with flexibility expiration time.

According to real options pricing theory, the value of flexibility increases if flexibility expiration time increases. Flexibility expiration time is the time from real options gained (purchased) to real options implemented. Hypothesis 4 is to evaluate whether manager's perception of this relationship is consistent with real option theory. Support for Hypothesis 4 can be indicated by a positive slope of flexibility expiration time versus perceived value of flexibility graph. A more specific description of this relationship that is tested in this research can be found in the Research Design section.

Hypothesis 5: Value of flexibility in project manager's perception is positively correlated with initial project investment (asset value).

According to real options pricing theory, the value of flexibility increases if initial project investment increases. Hypothesis 5 is to evaluate whether manager's perception of this relationship is consistent with Real option theory. Support for Hypothesis 5 can be indicated by a positive slope of initial project investment versus perceived value of flexibility graph. A more specific description of this relationship that is tested in this research can be found in the Research Design section.

The research captures managers' perceptions from this five hypotheses testing. Managerial practice of flexibility is tested from hypothesis 1 and hypothesis 3. Managers' perceived relationship of factors with value of flexibility is tested from hypothesis 2, hypothesis 4, and hypothesis 5. Due to unavailability of project managers as subjects all hypotheses are operationalized using the perceptions of subjects who participated in this experiment. There are more descriptions of subjects surrogated project managers in the Research Design Section.

4. RESEARCH METHODOLOGY

4.1. Research Method

To test the hypotheses and address the research questions a simulated simple uncertain installation project is developed. Research subjects were required to manage this uncertain project without and then with managerial flexibility. Subjects repeatedly value an option to avoid a slow and expensive system integration failure. Subjects were asked questions after managing the project. Questions are about how they made decisions during the game without and with flexibility, about how they valued flexibility and other questions related to their perception of flexibility. Performances and self-descriptions were analyzed to find out how subjects perceived and valued flexibility in an uncertain project. Policies were classified and their corresponding performances were compared. Hypotheses were tested based on data collected from the experiment and subjects' answers to the interview questions.

A system dynamics simulation model of the experimental project was developed to further analyze managerial flexibility practice. Simulations handled a range of uncertain conditions. The policies for using with and without flexibility to manage uncertainty that are used by participants were built into the model. Results of the simulations were used to evaluate policy effectiveness. Hypotheses tests and simulation results comparison were used to suggest developing and expanding operational real options theory and construction managers' practice in uncertain projects.

4.2. Research Design

4.2.1. Rig Installation Game (Experiment)

A simplified Rig Installation Game was used to create a simple project with uncertainty. The Rig Installation Game represents on-site installation of a semi-submersed, 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, etc. The game simplifies the complexity of system structure and installation of the rig system into 16 systems. These 16 systems are laid out as shown in the right side of Figure 1 from 1 to 16. The only system interface constraint is that each system installed should share an edge with a previously installed system. For example, if system 5 is installed, then system 1, 6, 9 could be installed. The 16 systems are built in different yards by different contractors.

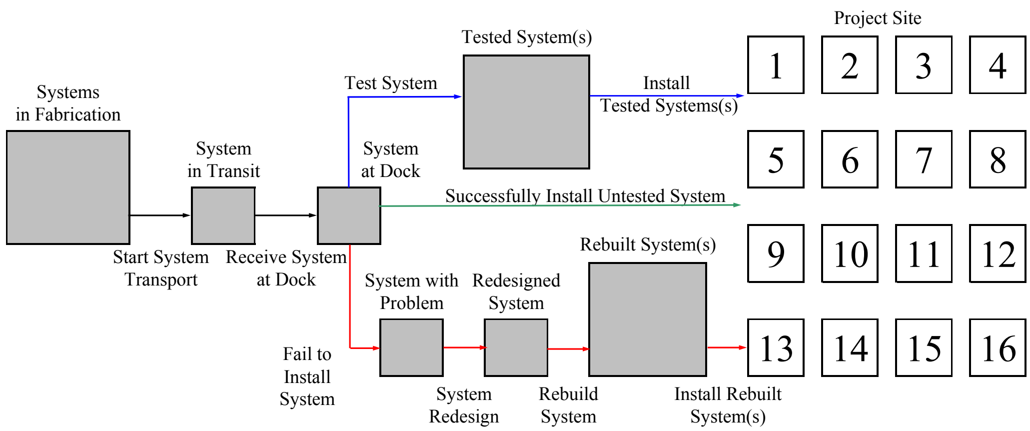


Figure 1 Experiment Game Board of Rig Installation Game

Each completed system leaves fabrication on different weeks, one system per week. In the experiment the unpredictable order of system arrival at the dock is the only uncertainty included. Dock and yards are expensive and scarce resources. This forces the manager to make a decision when each system leaves fabrication, before the manager knows if the system will meet the interface constraints or not. He must choose between reserving the yard to test the system or trying to install the system directly without testing. Each step in Figure 1 represented by an arrow takes one week. It takes two weeks to transport a system from fabrication to dock. Each week one system leaves fabrication. A decision is made when a system leaves fabrication and is exercised when a system leaves the dock. Each step between dock and site costs $10,000. If a manager decides to install the system without testing and the system meets the interface constraints then ‘Successfully Install Untested System’ is followed as shown by the middle path in Figure 1. To install a system successfully without testing only costs $10,000 (only one step taken). Alternately, if a manager attempts to install a system without testing and it does not meet the interface constraints, then the system will fail to install and must be redesigned and rebuilt before installation as shown by the bottom path in Figure 1. This path costs $40,000 to install the system (four steps involved). If a manager wants to test it before installation then it will cost $20,000 whether the system meets the interface constraints or not (two steps required). This path is shown in the top line in Figure 1. For a detailed game description and rules refer to Appendix A.

Managerial flexibility is provided in the game in the following way. Managers may delay their decision about whether to test a system or send it directly to the site, which means they are not forced to make a decision when a system leaves fabrication. Instead they make their decision when a system leaves the dock and the number of the system is revealed, which means managers make their decision after they know if the system meets the interface constraints. Therefore, delaying a decision can allow a manager to avoid slow and expensive installation failure. If they choose to delay the decision then they are charged an extra amount of money to delay the decision, which is defined as the cost of flexibility. The managers continuously evaluate the cost of flexibility for each system and make their decision of either accepting or rejecting flexibility. Flexibility cost starts at $2,000 and increases $1,000 for the next system's delay if managers accept delaying the current system decision and deceases $1,000 if managers reject the option to delay current system, with a minimum of $0.

The system storage fee, the fee to ship a system from fabrication to the doc etc are neglected. Systems that are tested in the yard or being rebuilt can be installed once they meet the system interface constraints.

4.2.2. Research Participants and Experiment Protocol

Due to time and resource constraints 21 graduate students, mainly from the Civil Engineering Department of Texas A&M University, participated in the experiment. Lack of real world experience is the primary limitation of using students as surrogates. However, in this experiment, real world experience is not an important factor for making decisions. Both students and project managers have the same level of knowledge necessary to play the Installation Game. Students and managers are expected to perform similarly on an information processing task such as the task in this experiment game (Ashton and Kraner, 1980; Khera and Benson 1970; Singh, 1998). $10 for compensation was given to each participant and a monetary prize for the top six performances was rewarded to encourage each participant to perform his best.

Each participant played one practice game without flexibility to get familiar with how the system works and how performance is measured. The game without flexibility is called the Rigid Game and the game with flexibility is called the Flexible Game. Then participants played two Rigid Games using their best strategies to achieve the lowest total installation cost. Performance was measured by the total cost; lower total cost indicates a better performance strategy. A sequence of pre-developed open questions regarding how participants made decisions was asked after the Rigid Games. These questions also included a self-assessment of levels of risk-aversion; more details are discussed in the Hypotheses Test section. For details of questionnaire refer to Appendix B.

After playing the Rigid Game, the participants were instructed to play the game with managerial flexibility (Flexible Game). The concept of flexibility in the game and the cost of flexibility were explained before playing a minimum of three and a maximum of six Flexible Games. During the game, participants continued to make decisions for each system under dynamic uncertainty. The average total costs of the Flexible Games were used to evaluate the participant's performance. Another sequence of pre-developed questions was asked of subjects after the Flexible Games. To assess how they made their decisions during the game an emphasis was placed on the difference between the Flexible Games and the Rigid Games. These questions also asked how they valued the flexibility, which factors they considered and their ideas of the relationship between the value of flexibility with uncertainty and other factors in Black-Scholes' equation (details of Black Scholes' equation factors refer to the Hypotheses section). The list of questions is attached in Appendix B. Experiment protocol is attached in Appendix C.

4.3. Simulation Model

A system dynamics based simulation model was developed of the Rig Installation Game. Uncertainty (random sequence of system leaving fabrication) was randomly generated by the computer. Extreme strategies were built into the model to test the model behavior in extreme conditions. Quantified policies for using without or with flexibility to manage uncertainty used by the subjects were built into the model. Simulation results of a wide range of uncertainty described with probability density function (pdf) graphs were used to test and compare policy effectiveness. For details of Model refers to Simulation Results section.

4.4. Data Analysis

Aggregate participants' performance, Rigid Game and Flexible Game separately, were statistically analyzed and described using mean, median, skewness, and variance. The average performance and one-sided t-tests between Rigid Game and Flexible Game and subject's perception of the differences between these two were used to test Hypothesis 1 (subjects value flexibility as an effective tool for managing uncertain projects). Subjects' perception of the differences between without and with flexibility games will be collected from the answers to the interview question: "If we ran many games will the average total cost with flexibility be [same, higher, lower] than without flexibility? Why?" Support for Hypothesis 1 can be indicated by the majority of subjects answering "lower". Their reasons would be similar to this example: "I think flexibility provided me a chance to successfully install a system without testing and no failure. And the cost of flexibility is much lower than either testing or failing to install the system." Support for Hypothesis 1 can also be indicated by experiment results of difference in mean performance between Rigid Game and Flexible Game.

To test Hypothesis 2 (subjects' perceived value of flexibility positively correlates with perceived uncertainty) graphs of cost of flexibility versus time (experiment results) and uncertainty versus time (simulation results) were drawn. Then, both graphs are integrated to analyze cost of flexibility vs. uncertainty.

There is a particular challenge in modeling perceived uncertainty in this experiment. A subject's perception of uncertainty is related to the ability to predict the outcome of a decision of directly sending to site. The outcome of sending a system to test is fixed, that is it costs \$20,000 to install a testing system. Two uncertainties are possible if system goes directly to the site, success (costs \$10,000) or failure (costs \$40,000). Relative certainty about either success or failure reduces perceived uncertainty. Therefore perceived uncertainty is low when either the probability of success (p(s)) is very high or the probability of failure (p(f)) is very high (same as p(s) very low) for direct installation of the next system. P(s) is very high at the end of the game when many systems have been installed. P(s) is very low at the beginning of the game when few systems have been installed. Only in the middle of the game, p(s) is not very low and not very high, then the predictability of the outcome is low, which means subjects perceived uncertainty as high. Therefore, the graph of uncertainty to subjects over time is an inversed "U". Therefore Hypothesis 2 can be supported if the graph of perceived value of flexibility versus time has an inversed "U" shape.

To test hypothesis 3 (differences in levels of risk-aversion impact the perceived value of flexibility), data were categorized according to a subject's level of risk-aversion based upon his self-assessment, investigor's observation, and actions during the experiment. An extreme risk-averse and risk-seeking manager's policy and performance pdf graph were explained to subjects. Extreme risk-averse manager never sends a system directly to site when the system might fail to install in the Rigid Game, while extreme risk-seeking manager never tests a system in the Rigid Game. Performance pdf graphs of the extreme policies were generated from the simulation model.

Subjects were asked to self-assess which of the following category they were: risk-averse, risk-neutral or risk-seeking. Then, the same level of risk-aversion subjects' performance was analyzed aggregated to compare performance among different levels in the Rigid and Flexible Game. In the Flexible Game, the average cost of flexibility of risk-averse people and risk-seeking people were calculated and compared to each other. Also interview questions about how they valued flexibility and how much they would like to pay during the Flexible Game were asked. The question posed to subjects is: "If you are the person who decides the Cost of Flexibility for each system, what will be the maximum you would like to pay? Why? Does it change during the game from the beginning to the end. [Constant, decrease, increase, other?] Why?" Support for Hypothesis 3 can be indicated by a difference in the graph of the average cost of flexibility between risk-averse subjects and risk-seeking subjects. It can also be indicated by the significant difference in the average maximum cost in the subject would like to pay from different levels of risk-aversion.

To test Hypothesis 4 (the value of flexibility in subjects' perception is positively correlated with flexibility expiration time), the following interview question was asked: "If you played the Flexible Game again exactly as we just did EXCEPT that it takes four weeks instead of two weeks to transport systems from Fabrication to Dock, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?" Support for Hypothesis 4 can be indicated by the majority of subjects answering similar to "Yes, more delay is preferred and higher net savings is expected."

To test Hypothesis 5 (the value of flexibility in subjects' perception is positively correlated with asset value), the following interview questions were asked: "If you played the Flexible Game again exactly as we just did EXCEPT that each operation cost $5,000 instead of $10,000, and the flexibility cost is half of what it was previously, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?" Support for Hypothesis 5 can be indicated by the majority of subjects answering similar to "I would keep the same strategy since there is only a scale difference as before (both asset value and vale of flexibility decreased as half value as before)". A further question was asked: "Suppose you are the project manager of a small construction company, will you use different flexibility policies between a small project and a large project. Supposing the failure of the large project will lead to the bankruptcy of your company." Support for Hypothesis 5 can be indicated by the majority of subjects answering similar to "I would a use different strategy, and would prefer more flexibility in large projects."

Finally, policies were quantified according to subjects' levels of risk-aversion, answers to interview questions, experiment performances and investigator's observations. Quantified policies were built into the simulation model. Simulation results were statistically analyzed to evaluate and compare policy effectiveness.

5. RESULTS

Results are presented in two sections. The first section presents experiment results. The second section presents simulation results.

5.1. Experiment Results

Experiment results are collected from 21 subjects. Participants spent an average of two hours on the experiment. In total, there are 42 Rigid Games with two Rigid Games for each participant and 83 Flexible Games total with each participant having played 3~6 Flexible Games. One game was deleted from the results because of a subject's misunderstanding of flexibility. Results are separated into two groups: Rigid Game and Flexible Game. Subjects are categorized into three levels of risk-aversion: risk-averse, risk-neutral and risk-seeking. Statistical analyses were conducted comparing performance of Rigid Game and Flexible Game and comparing the behavior and performance of different levels of risk-aversion.

5.1.1. Hypotheses Test and Exploratory of Experiment Results

Hypotheses 1 Test: Subjects value flexibility as an effective tool for managing uncertain projects

This hypothesis was tested with two sets of data: game performance and subject interview answers. Support for this hypothesis is demonstrated with game performance data if the mean Flexible Game performance is better than the mean Rigid Game performance. Aggregated subjects' performance in the Rigid Game and the Flexible Game separately were analyzed statistically as shown in Table 2. F-test for significant statistical variance difference between the Rigid and Flexible Game performance was performed. There is no strong evidence to reject that they have similar variance at level 0.05 due to $p=0.0984$, and therefore the t-test (Two sample assuming equal variance) was used to test the hypothesis. One-sided t-test for statistically significant difference between the means of the Rigid and Flexible Game was performed. There is strong evidence that Flexible Game performance is better than Rigid Game performance at level 0.05 due to $p=0.0006$. Considering personal behavior diversity, performance comparison between Flexible Game and Rigid Game by person is compared by using paired T-test. Paired T test by person results p = 0.00022 shows significant difference between the means of the Rigid Game and Flexible Game performances by person. Therefore, Hypothesis 1 is supported. For detailed performance of each game refer to Appendix D.

Table 2 Experiment Performance of Rigid Game vs. Flexible Game

	Rigid	Flexible
Mean Total Cost ($1,000)	270	247
Standard Deviation	39.97	33.76
Skewness	0.68	0.99
Count (n)	42	82
Variance Significant Difference (F-test)	p=0.0984	
Mean Significant Difference (t-test)	p=0.0006	
Paired T-test by person	p=0.00022	

Note: If $p<0.05$ in F-test, there is strong evidence to reject H_0 of same variance at level 0.05, otherwise there is no strong evidence to reject H_0 of same variance in F-test.

If $p<0.05$ in t-test, there is strong evidence to reject H_0 of same mean at level of 0.05, otherwise there is no strong evidence to reject H_0 of same mean in one-sided t-tests.

Subjects' perceptions of flexibility as an effective tool in managing uncertain projects were collected from the answers to the interview question: "If we ran many games will the average total cost with flexibility be [same, higher, lower] as (than) without flexibility? Why?" All twenty one participants answered "lower". For details of subjects' answers refer to Appendix E.

Subjects' ideas are summarized as follows:

1) Flexibility provided a chance to get more information for decision making, which decreased the probability of failure and increased the likelihood of successful system installation without testing

2) The cost of flexibility was relatively lower compared to the cost of failure ($40,000 to install the system) or the cost of testing a system ($20,000 to install

the system). The average cost of flexibility to delay a decision in 82 Flexible Games played by subjects was $1,850. For details of flexibility cost refer to Appendix F.

Therefore, flexibility is perceived as an effective tool for managing uncertain projects by subjects. Hypothesis 1 is strongly supported by the experiment results.

Hypothesis 2 Test: Subjects' perceived value of flexibility positively correlates with perceived uncertainty

This hypothesis was tested with three types of data: subjects' decisions during games, subject interview data and simulation results. Subject decisions during the experiment were used to test this hypothesis by separately modeling and then comparing subjects' perceived value of flexibility and subjects' perceived uncertainty over the duration of a single game.

Perceived value of flexibility was modeled with average costs paid/not paid by subjects for flexibility each week in 82 Flexible Games. The perceived minimum average $cof ceiling versus time line means subjects maximum perception of the flexibility value is no less than this line. Because this line is the average of the $cof when subjects delayed the decision (that is, $cof is the minimum ceiling that the subject would like to pay) and $0 when subjects did not delay the decision (that is, subjects definitely would delay the decision when $0. Therefore, $0 is the minimum ceiling he would like to pay.). The perceived maximum average $cof ceiling versus time line means subjects maximum perception of the flexibility is less than this line. Because this line is the average of $12,000 when subjects delayed the decision and $cof when subjects did not delay the decision. $11,000 is the maximum $cof subjects actually paid in 82 Flexible Games, therefore $12,000 is used as the maximum perception of the flexibility of subjects when subjects delayed the decision. Based on above analysis, subjects' perception of flexibility value fell into the area between the minimum line and maximum line. An inversed 'U' of the average costs of flexibility area over time is observed from Figure 2. The X axis represents weeks during the installation game. The Y axis represents the average cost of flexibility paid by subjects.

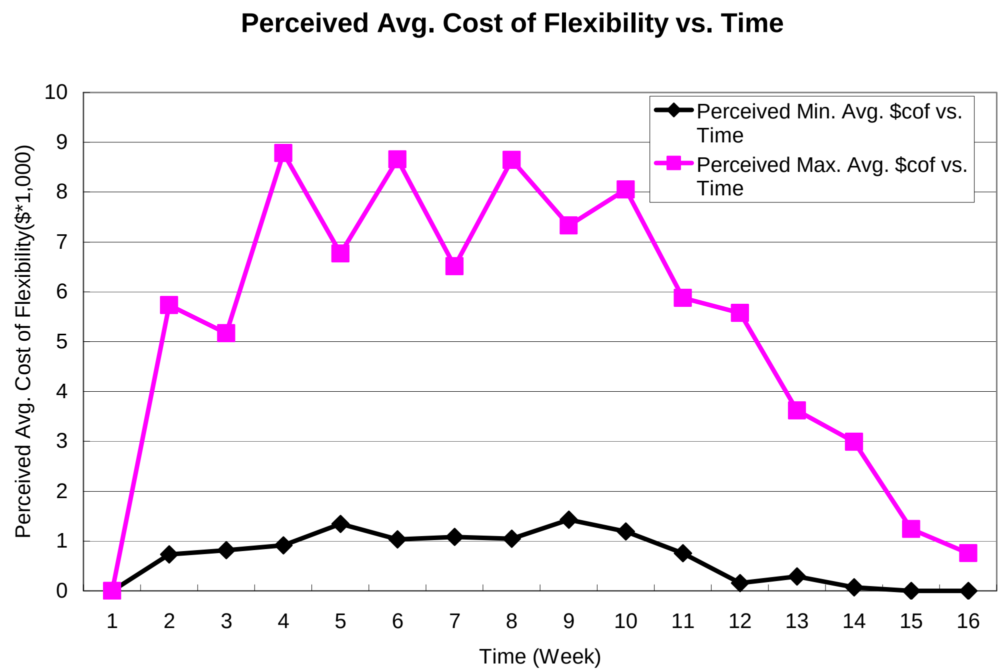
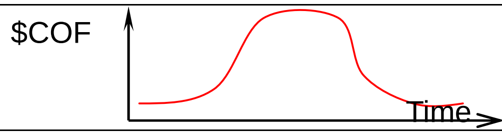
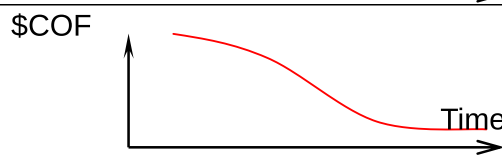


Figure 2 Experiment Cost of Flexibility vs. Time

Subjects' answers to interview questions about their policies in Flexible Games also support Hypothesis 2. Thirteen of 21 subjects stated that they would not pay in the beginning and end of the game when either p(successful) or p(fail) was very high. p(fail) is very high in the beginning of the game when only few systems were installed. They did not delay the decision unless it cost $0, because the system would most likely be tested anyway. At the end of the game, when most systems were installed, p(successful) was very high, they thought it was not worth paying extra money to delay the decision. They preferred paying more in the middle of the game when it was difficult to predict the outcome of attempting to install the system directly (i.e. when uncertainty was relatively high). Three out of 21 subjects stated they would like to pay more in the beginning of the game and the value of flexibility decreased over time. One of the subjects described the reason for his decision to decrease $COF over time as: "everything was unclear early in the game". Three out of 21 subjects evaluated the flexibility value as constant over time during the game.

Therefore, the majority of subjects perceived the flexibility value as positively correlated with perceived uncertainty, which supports Hypothesis 2. Table 3 summarized the answers.

Table 3 Subject's Perceived Maximum Value of Flexibility Over Time

No. of Subjects	**Perceived $COF vs. Time**
13	
3	
3	
2	No Idea

Subjects' perceived uncertainty was modeled using the simulation model (see Model Structure section for details of model description) as follows. Experiment results indicate a subject's perception of uncertainty is negatively correlated to the ability to predict the outcome of a decision of either testing or directly sending a system to site. Perceived uncertainty is low when either the probability of successful [p(s)] is very high or probability of fail [p(f)] is very high. Therefore, uncertainty can be modeled as:

$$Uncertainty = min(p(s), p(f))$$

Uncertainty over time pdf graphs from 200 simulations is shown in Figure 3, as an inversed 'U'. The system decisions during the simulation games are based on using an extreme risk-averse strategy in the Rigid Game: never sending a system to site when the system might fail to be successfully installed and there is no flexibility provided. Other decision policies can be used to test uncertainty over time in the game in future research. For details of model and equations of Uncertainty refer to Appendix J.2.

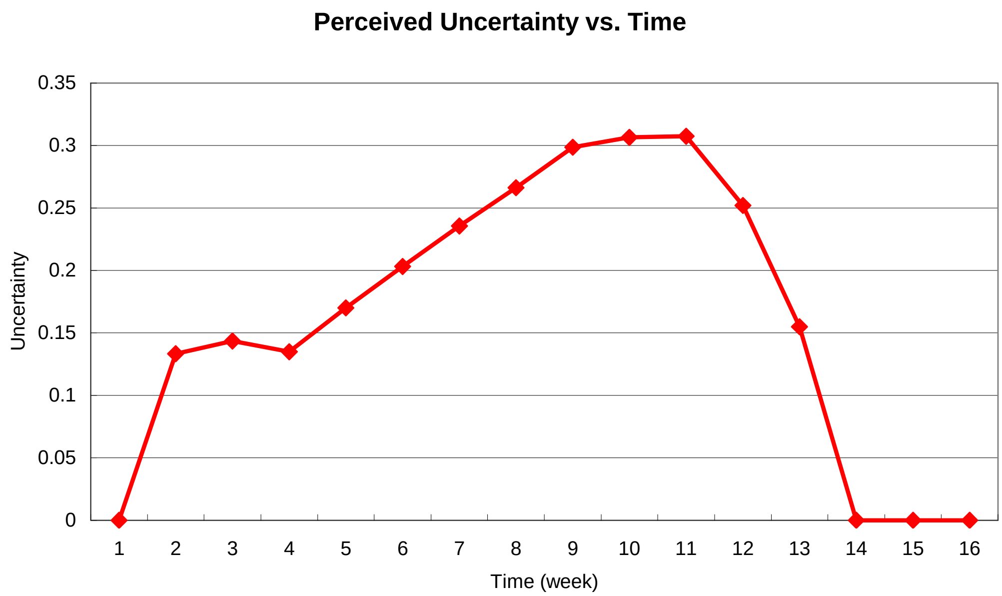


Figure 3 Simulated Uncertainty vs. Time

The similarity in the slopes of Figure 2 and Figure 3 (both are inversed 'U') supports Hypothesis 2. A more direct way to compare Figure 2 and Figure 3 is shown in Figure 4. The peaks of two inversed 'U' do not appear at exactly the same time. Perceived average cost of flexibility's peak for both minimum line and maximum lien are earlier than the simulated uncertainty peak. One reason may be that the simulation model does not exactly simulate the experiment condition. The other possible reason is that subjects potentially overestimate uncertainty in the beginning of the game because few systems installed on the project site and they potentially underestimate uncertainty at the end of the game when most systems installed on the project site. According to Bounded Rationality Theory, people are only partly rational, and are emotional/irrational in parts of their decisions making, because there are limits to formulating and processing knowledge to solve complex problems, especially when continuous decisions need to be made (Simon, 1978). Future research could investigate this phenomenon.

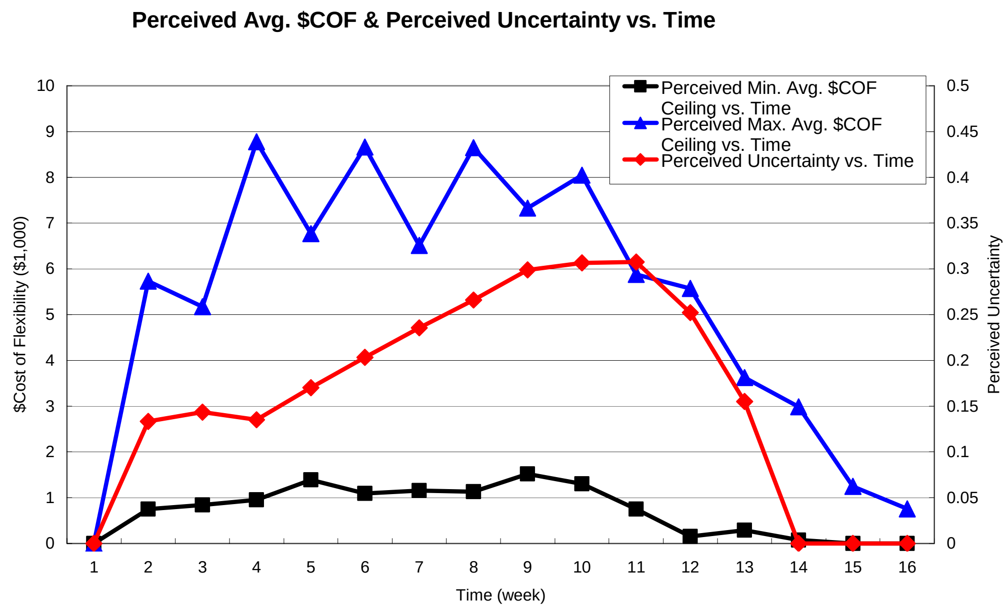


Figure 4 Perceived Average Cost of Flexibility vs. Perceived Uncertainty

Again could be drawn for each individual's perception of cost of flexibility and uncertainty. But due to only 3~6 games played by one subject, there is no enough data to get significant statistical results, which is one of the experiment limitations. Future research can conduct experiments with more games played by one subject to allow analysis based on the subject instead of on games.

Also at the end of the experiment, subjects were asked an interview question about a change in using flexibility if the system interface constraints changes: "If you played the Flexible Game again exactly as we just did EXCEPT systems that would share a corner with a previously installed system can be successfully installed as well as systems that would share a edge, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?" Uncertainty decreases in the question assumption. 20 out of 21 subjects believed the value of flexibility would be worth less since uncertainty decreases. Hypothesis 2 is supported by the experiment results. For details of answers refer to Appendix G.

Therefore, a subject's perceived average cost of flexibility is positively correlated with perceived uncertainty. Hypothesis 2 is supported by the experiment results.

Hypothesis 3 Test: Differences in levels of Risk-aversion impact the perceived value of flexibility.

Twenty one subjects were classified into three levels of risk-aversion: risk-averse, risk-neutral and risk-seeking based on their self-assessments, investigor's observations, and their actions during the experiment. Subjects were asked to self-assess their level of risk-aversion after they played one practice Rigid Game and two Rigid Games with their best strategies. In the Rigid Game, risk-averse people are identified as subjects who rarely sent a system directly to site when the system might fail to meet the constraints. Risk-averse strategy is defined as an extreme risk-averse level strategy, because in this strategy, people never take a risk to send a system to site when it might fail to install. This definition was provided to subjects as an example of extreme risk-averse level manager's strategy. Risk-neutral people are identified as subjects who sometimes send a system directly to site when the system might fail in the Rigid Game. "If there is a 50% chance of success (if system is installed directly), I would randomly decide to either send to site or to test the system (in the Rigid Game)" stated one subject whose self assessment was risk-neutral. Risk-seeking people are identified as subjects who often send a system directly to the site when the system might fail to meet the constraints in the Rigid Game. All-Guts strategy, sending all systems directly to site, is defined as an extreme risk-seeking level strategy. This definition was provided to subjects as an example of extreme risk-seeking level strategy. In total, the experiment included 11 risk-averse subjects, two risk-neutral subjects, and eight risk-seeking subjects as shown in Table 4. But none of the twenty one subjects was extremely risk-averse or risk-seeking individuals who never or always sent a system to the site when the system might fail to meet the constraints.

Table 4 Risk-aversion Assessment

Participant No.	Self-Assessment (Risk Averse?)	Investigator's Observation	Rigid Game Performance	Flexible Game Performance	Notes
1	1	1	2	1	
2	?	3	4		
3	?	3	4	4	Subject's strategy is not stable. Sometimes he randomly made decisions
4	1	1	2	2	
5	2	2	3		if p(s)=50%, subject randomly decided 'to Site' or 'to Test'
6	?	3	4	3	
7	?	3	4		
8	1	1	2		
9	?	2	3		
10	1	1	2		"if p(f)=2/8, then decision is 'to Site'; if p(f)= 2/7, then decision is 'to Test'" stated by the subject
11	3	3	4		
12	3	3	4		
13	3	3	3	4	Between Neutral to Seeking in Rigid Game, moving to Seeking in Flexible game
14	3	3	4		
15	1	1	2		subject's 1st Flexible Game is delete because of subject's misunderstanding of cost of flexibility
16	1	1	2		
17	1	1	3	1	Between Averse and Neutral; Neutral in Rigid game, moving to Averse in Flexible Game
18	1	1	2		
19	1	1	2		
20	1	1	2		Between Averse and Neutral
21	1	1	2		

Note: Self-Assessment and Investigator's Observation Columns: ?-No self-assessment; 0: Can Not Tell; 1:risk-averse; 2:risk-neutral; 3:risk-seeking

Rigid Game Performance and Flexible Game Performance Columns: how often subjects sent a system to site when it might fail to install? 1:Never; 2:Rarely; 3:Sometimes; 4:Oftern; 5:Always

In Rigid Games, risk-seeking subjects sent more systems directly to site than risk-averse subjects, since they prefer risk, as shown in Figure 5. Due to the fact that only two subjects are risk-neutral, the result has no significant statistical meaning. Risk-neutral is dropped out in later comparison of experiment results. The comparison between the risk-averse and the risk-seeking is good start for this preliminary research. Future research can collect more data and add risk-neutral level comparisons.

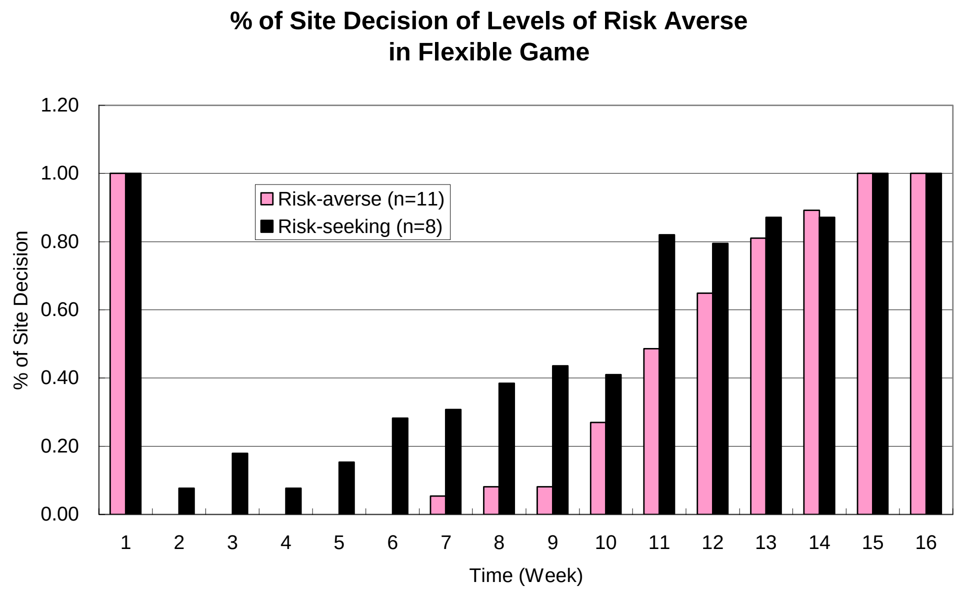


Figure 5 Percentage of Site Decision of Levels of Risk-averse in Rigid Game in the Experiment

Graphing the cost of flexibility over time of levels of risk-aversion reveals that subjects may behave systematically different in the first and second half of a single game. Figure 6 shows the difference in the average minimum average cost of flexibility ceiling over time among different levels of risk-aversion. Maximum average cost of flexibility ceiling is not compared because the maximum ceiling when subjects did not delay decisions is hard to define for different levels based on current experiment data. Risk-seeking subjects had higher minimum average cost of flexibility ceiling in the beginning of the game than risk-averse subjects from analysis.

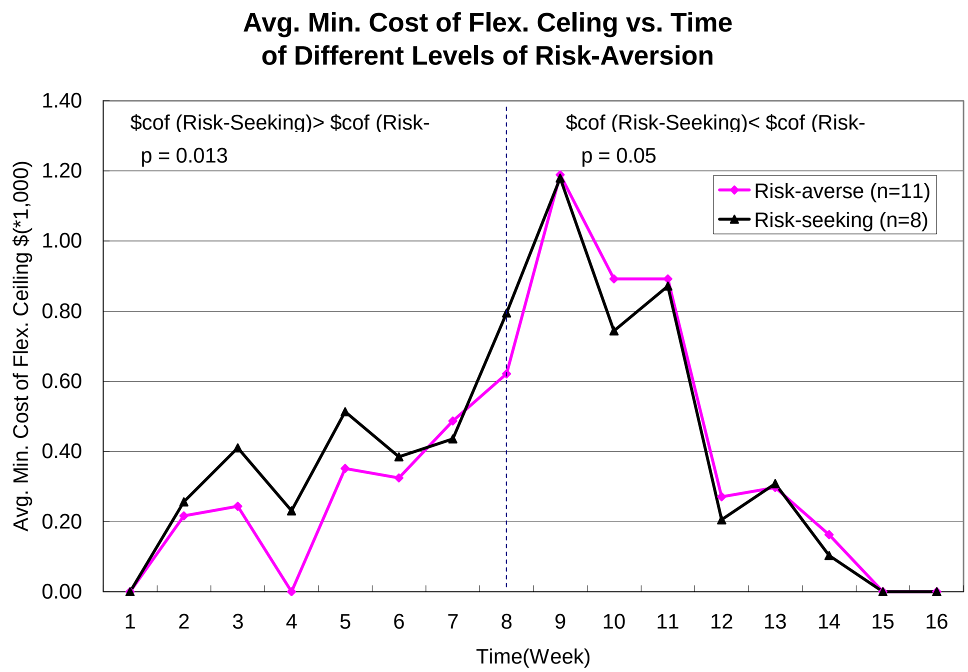


Figure 6 Average Minimum Cost of Flexibility Ceiling vs. Time of Different Levels of Risk-aversion in the Experiment

Statistical F-tests and one-sided t-tests were performed for the first eight weeks and second eight weeks of the difference in average minimum cost of flexibility ceiling among levels of risk-aversion as shown in Table 5. P-values show there is a significant difference in the average minimum cost of flexibility ceiling difference between risk-averse and risk-seeking levels in the first eight weeks. Risk-seeking subjects have a higher average minimum cost of flexibility ceiling value than Risk-averse subjects. In the later eight weeks, there is no significant difference of the average minimum cost of flexibility ceiling value between risk-seeking and risk-averse. Hypothesis 3 is supported by the experiment results from the first half of the experiment. Future research could collect more data to further investigate this result.

Table 5 Comparison of Average Minimum Cost of Flexibility Ceiling vs. Time of Different Levels of Risk-aversion in the Experiment

Week 1-8 of Flexible Game

Strategy	Risk-averse	Risk-seeking
Mean $cof	0.280	0.378
Standard Deviation	0.047	0.054

p-value for F-test	Averse	Seeking
Averse	---	
Seeking	0.432	---

p-value for t-tests	Averse	Seeking
Averse	---	
Seeking	0.013	---

Week 9-16 of Flexible Game

Strategy	Risk-averse	Risk-seeking
Mean $cof	0.463	0.354
Standard Deviation	0.211	0.178

p-value for F-test	Averse	Seeking
Averse	---	
Seeking	0.471	---

p-value for t-tests	Averse	Seeking
Averse	---	
Seeking	0.046	---

Unit: $1,000 for Mean $COF

In the Flexible Game, risk-seeking subjects would like to delay decisions at the beginning to increase the probability of sending the system directly to site even though the probability of testing the system two weeks later was very high. Risk seekers focus on how to successfully install system. On the other side, risk-averse subjects prefer to test the system in the beginning of the game, because they did not want to pay the extra money to delay the decision, with the high probability of testing the system two weeks later. Risk-averse subjects focus on how to limit local costs.

Hypotheses 4 and 5 testing introduction: Subjects were asked questions to determine if they perceived other factors influencing the value of flexibility besides uncertainty. The factors represent factors in Black-Scholes' equation. Factors considered in this research include uncertainty, flexibility expiration time, and initial project investment (asset value).

Hypothesis 4 Test: Value of flexibility in subject's perception is positively correlated with flexibility expiration time.

An interview question about a change in using flexibility if the time between the system leaving fabrication to arriving at the dock increases was asked: "If you played the Flexible Game again exactly as we just did EXCEPT that it takes four weeks instead of two weeks to transport systems from Fabrication to Dock, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?"

Expiration time of flexibility increases from two weeks to four weeks in the question assumption. Real options theory would indicate the value of flexibility increases because uncertainty increases. Table 6 shows the interview results of changing in using of flexibility and net saving if duration from system leaving fabrication to dock increases in the experiment (Flexibility expiration time increases). For example, four subjects would decrease the number of delays and net savings would decrease if flexibility expiration time increases. A statistical one-sided sign test for the number of delays shows there is no strong evidence to reject the null-hypothesis due to $r^- = 6$ larger than $r^*_\alpha = 3$ at level of $\alpha = 0.05$ when $n = 14$. The null-hypothesis is that subjects' perception of the number of delays is the same if flexibility expiration time increases. Statistical one-sided sign test for net savings shows there is no strong evidence to reject the null-hypothesis due to $r^- = 4$ equal to $r^*_\alpha = 4$ at level of $\alpha = 0.05$ when $n = 17$. The null-hypothesis is that subjects' perception of net-savings is the same if flexibility expiration time increases. Therefore, Hypothesis 4 is not strongly supported by the experiment results. Subject's perception of value of flexibility and flexibility expiration time is not positive correlated. For details of answers refer to Appendix H.

Table 6 Change in Using of Flexibility and Net Savings if Duration from System Leaving Fabrication to Dock Increases in the Experiment

		Net Savings				**Total**
	No. of Subjects	**Lower**	**Same**	**Higher**	**No Idea**	
No. of Delays	**Lower**	3			1	4
	Same		3			3
	Higher	2		8	3	13
	No Idea	1				1
Total		6	3	8	4	21

Hypothesis 5 Test: Value of flexibility in subject's perception is positively correlated with asset value.

The interview question about the change of use flexibility if unit costs are lower is: "If you played the Flexible Game again exactly as we just did EXCEPT that each operation cost $5,000 instead of $10,000, and the flexibility cost is half of what it was previously, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?" Asset value and flexibility price are half the previous price in the question assumption. Real options theory would indicate that no changes would happen because there is only scale difference. Table 7 shows the interview results of changing use of flexibility and net savings if unit costs and exercise costs are both lower in the experiment. For example, only one subject would decrease the number of delays and net savings would decrease in these conditions. Statistical two-sided sign test for the number of delays shows there is no strong evidence to reject the null-hypothesis due to $r^{-} = 1$ larger than $r^{*}_{\alpha} = 0$ at level of $\alpha = 0.05$ when $n = 3$. The null-hypothesis is that subjects' perception of the number of delays is the same if cost changes in scale. Statistical two-sided sign test for net savings shows there is no strong evidence to reject the null-hypothesis due to $r^{-} = 1$ equal to $r^{*}_{\alpha} = 0$ at level of $\alpha = 0.05$ when $n = 5$. The null-hypothesis is that subjects' perception of net-savings is the same if cost changes in scale. Therefore, experiment results do not object Hypothesis 5. For details of answers refer to Appendix I.

Table 7 Change in Using of Flexibility and Net Savings if Units Costs and Exercise Costs Are Both Lower in the Experiment

		Net Savings				**Total**
	No. of Subjects	**Lower**	**Same**	**Higher**	**No Idea**	
No. of Delays	**Lower**	1				1
	Same		16			16
	Higher			2	2	4
	No Idea					0
Total		1	16	2	2	21

A further question was asked of some subjects after the previous question: “Suppose you are the project manager of a small construction company, will you use different flexibility policies between a small project and a huge project. The failure of the huge project would lead to the bankrupt of your company”. Real options theory would indicate the value of flexibility in small project is less than in huge project because small asset value. 10 out of 11 subjects answered they would prefer flexibility in the huge project, “Since we couldn’t afford a failure in a huge project,” as described by one subject. Hypothesis 5 is supported by the experiment results.

Summary

All hypotheses are designed to capture a subject’s perception of the value of flexibility.

- Hypotheses 1 (Subjects value flexibility as an effective tool for managing uncertain projects) was supported by experiment results.
- Hypothesis 2 (Subjects’ perceived value of flexibility positively correlates with perceived uncertainty) was supported by experiment results.
- Hypothesis 3 (Differences in levels of risk-aversion impact the perceived value of flexibility) was supported by experiment results for the first half of the experiment.
- Hypothesis 4 (Value of flexibility in subject’s perception is positively correlated with flexibility expiration time) was not strongly supported by experiment results.
- Hypothesis 5 (Value of flexibility in subject’s perception is positively correlated with asset value) was supported by experiment results.

5.1.2. Performance of Experiment

Experiment performance of Rigid Game and Flexible Game and levels of risk-aversion are compared in this section.

5.1.2.1. Performance of Rigid Game versus Flexible Game

Rigid Game and Flexible Game performances from the experiment are summarized in Table 8, as discussed in the Hypotheses Tests section. The Rigid Game and Flexible Game have a similar variance (p=0.0984). But the Flexible Game has a better average performance (lower average total cost) (p=0.0006).

Table 8 Experiment Performance

	Rigid	Flexible
Mean Total Cost ($1,000)	270	247
Standard Deviation	39.97	33.76
Skewness	0.68	0.99
Count (n)	42	82
Variance Significant Difference (F-test)	p=0.0984	
Mean Significant Difference (t-test)	p=0.0006	

5.1.2.2. Experiment Performance of Different Levels of Risk-aversion

The performance of each level of risk-aversion in the Rigid Game was compared, as shown in Table 9. F-test was performed to compare the variances. Because there are only four data for the risk-neutral level, comparisons with this level do not have significant statistical meaning. Risk-averse and risk-seeking levels have similar variance in the Rigid Game due to p=0.23 in F-tests. T-test for assuming equal variance was used and the result shows that there is no significant difference of average performance in the Rigid Game between risk-averse and risk-seeking subjects due to p=0.17 in one-sided t-test.

Statistical F-test and one-sided t-tests were performed on Flexible Game performance among levels of risk-aversion as shown in Table 10. Risk-averse and risk-seeking levels have a significant difference in variance in the Flexible Game due to p=0.0000014 in F-tests. There is a significant difference in the average performance in the Flexible Game between the risk-averse and risk-seeking level due to p=0.0002 in the one-sided t-tests assuming unequal variance.

Table 9 Experiment Average Performance of Levels of Risk-aversion in Rigid Game

Strategy	Risk-averse	Risk-seeking
Mean Total Cost ($1,000)	263	275
Standard Deviation	35.35	41.79
Skewness	1.32	-0.03
Count (n)	22	16

p-value for F-test	Averse	Seeking
Averse	---	
Seeking	0.23	---

p-value for t-tests	Averse	Seeking
Averse	---	
Seeking	0.17	---

Table 10 Experiment Average Performance of Levels of Risk-aversion in Flexible Game

Strategy	Risk-averse	Risk-seeking
Mean Total Cost ($1,000)	234	260
Standard Deviation	17.31	39.37
Skewness	0.32	0.33
Count (n)	37	39

p-value for F-test	Averse	Seeking
Averse	---	
Seeking	0.0000014	---

p-value for t-tests	Averse	Seeking
Averse	---	
Seeking	0.0002	---

However, subjects' perception of the maximum value of flexibility collected by the interview question does not indicate that there is a difference in maximum flexibility value among levels of risk-aversion. For detailed values refer to Appendix E.

5.1.3. Quantified Policies

Policies were quantified for the three levels of risk-aversion: risk-averse, risk-neutral and risk-seeking as classified in the Hypotheses Test section. Policies include Rigid Game policies and Flexible Game policies based on subjects' answers and investigator's observations to the interview questions after they played the Rigid Games and Flexible Games.

Rigid Game policies of 21 subjects are summarized in Table 11. All subjects considered systems installed on site and the distribution of those systems. 14 of 21 subjects considered systems leaving dock but have not been installed. 12 of 21 intuitively calculate the probability of failure for the next system leaving fabrication. Subjects estimated p(f) considering systems installed on site and/or system leaving dock that the number of the system were revealed. Even though most subjects did not really do the math for each decision during the game, they considered p(f) more or less for making decisions.

Risk-seeking subjects were willing to take more risk than risk-averse subjects from Table 11. Figure 5 in Hypothesis Test section also verifies that during Rigid Game, risk-seeking subjects sent higher percentage of systems to site than risk-averse subjects. In summary, in Rigid Game, subjects mainly considered the p(f) for the system leaving fabrication to make a decision. They sent a system to site when p(f) was under their acceptance risk range, and the main difference of different levels of risk-aversion is that they have different acceptance risk ranges. Risk-seeking subjects' acceptance range is higher than risk-averse subjects'.

Table 11 Subject's Rigid Game Policies Summary

		Considering Parts				Sites?		
Participant No.	Level of Risk-Aversion	Sys. On Site	Sys. On Board	P(fail)?	Cost of Installation Path	Beginning of the Game	End of the Game	Notes
1	1	X	X	X	X			
4	1	X	X		X	2		
8	1	X	X	X				site(first)-test(couple of sys.)-site/test(try risk, if the system failed then I would test more)-site
10	1	X	X	X				site(first)-test-site(if p(f)<2/8)
15	1	X	X	X	X	2	2	site-test(middle)-site(once got key card)
16	1	X	X	X		2	2	if p(fail)<50% decision was 'to Site'. I tried my best to avoid failure
17	1	X	X	X		1~2	2~3	if p(s)>60%, decision was 'to Site'; once started to send a system to site, I would almost continue 'to Site'
18	1	X	X	X		1~2	2~3	if p(s)>50%, decision was 'to Site', consider increase p(s)to 60% or 70% for 'to Site' decisions
19	1	X	X			2	2	site-test(middle)-site(when lots of cards on Test is scattered)-site(end)
20	1	X			X	2	4~5	if p(f)<50%, took chance 'to Site', if failed then test couple more; last 5 cards always 'to Site'
21	1	X	X	X		1	3	Fail to install a system would delay the whole installation process. '; less than 3 system might fail to install, decision would be 'to Site'
5	2	X						Test many systems would delay the whole installation process. site(first)-test(4~5)-site(if failed, test more system)
9	2	X	X		X			Fail to install a system would delay the whole installation process.
2	3	X			X			if 2 system failed when I start sent systems to site then I would test more system before sending system to site again
3	3	X	X					Fail to install a system would delay the whole installation process. If couple systems failed, then I will test more systems
6	3	X	X	X				risk subject would like to take was high
7	3	X		X				site(first)-site/test(first sys. Center, then site, otherwise test)-site (start from middle)
11	3	X		X	X			site(first)-test-site /test(if one system failed, I would test more because I couldn't afford more failure)-site
12	3	X				4	5	site(couple of them)-test(if couple of 'to Site' systems failed)-site
13	3	X	X	X	X			site/test in the middle, if fail couple of them, then go back to test considering the high cost of failure
14	3	X				4	5	Most time I took risk, if first card was in the center of site, then I would send more systems to Site

Note: Considering Parts: lists the parts subjects considered when they made decisions in Rigid Game
Sys. On Site: Subjects considered number of systems installed on site and the distribution of installed systems of site
Sys. On Board: Subjects considered systems left dock, that is the number of the system is known but the systemhas not installed on site
p(fail): subjects stated that they calculate the probability of failure to help their decision
Cost of Installation Path: Subjects considered the difference in cost of three installation paths
Sites? : lists about how often subjects sent a system directly to Site when installation might fail
Beginning of the Game: the first eight weeks of the game
End of the Game: the later eight weeks of the game
Sites? Column: how often subjects sent a system to site when it might fail to install? 1: never; 2: rarely; 3: sometimes; 4: often; 5: always

Flexible Game policies of 21 subjects are summarized in Table 12 with emphasizing on difference from Rigid Game policies. All subjects considered cost of flexibility when they made decisions in the Flexible Game even though they might consider it in different ways. Twelve of 21 subjects stated that they would definitely delay decision if cost of flexibility was $0. Ten of 21 subjects claimed that 'if I did not delay first couple of systems, then the cost of flexibility would decrease to zero (according to the rules of cost of flexibility)' or 'the cost of flexibility increased after

I delayed couple of systems, then I thought it was no longer worth to delay the decision at that higher price.' Nice of 21 subjects described that compared to the cost of installing a failed system ($40,000) or installing a tested system ($20,000), the cost of flexibility ($2,000 or $3,000) was cheaper. They said it was worth the extra expense to spend a relatively small amount of money to avoid spending more money to test systems. In summary, in the Flexible Game, subjects mainly considered the p(f) for the system leaving fabrication as they did in Rigid Game and the cost of flexibility to make a decision. They delayed a system decision when the uncertainty was high and the cost of flexibility was reasonable and they sent a system to site when p(s) was high or tested a system when p(f) was high. The main difference between different levels of risk-aversion is that they have different perceptions of value of flexibility under the same condition of uncertainty as discussed in the Hypotheses Test section. Based on subjects' answers (Table 11 and Table 12) and investigator's observations from both the Rigid Games and Flexible Games, following is concluded. Further research would verity this conclusion. The primary concern of risk-averse subjects was the certainty of success or failure of the next system sent to site. The cost of flexibility is of secondary importance to risk-averse subjects when making decisions. However, risk-seeking subjects regarded certainty as less important than risk-averse subjects. Risk-seeking subjects' primary concern is the cost of flexibility.

Table 12 Flexible Game Policies Summary

		Considering Parts (Emphasis on Difference from Rigid Game)							Sites?		
Participant No.	Level of Risk-Aversion	Sys. On Site	Sys. On Board	P(fail)?	Cost of Installation Path	$COF=0	$COF increase?	$COF vs. $fail or $test	Beginning of the Game	End of the Game	Notes
1	1	X	X	X	X		X	X			
4	1	X	X		X		X				
8	1	X	X	X		X	X				never pay money to delay except when $COF=0. But I paid $COF=1in the 3rd game, just taking a chance to increase p(s)
10	1	X	X	X		X					if p(s)>=75%, then decision would be 'to Site' no delay
15	1	X	X	X	X	X		X	1	1	
16	1	X	X	X		X			2	2	if p(f)>0.25, then decision would be 'to Site' no delay
17	1	X	X	X		X	X	X	1	3	
18	1	X	X	X		X		X	1	3	if p(s)>=50% & $COF >=2, then decision would be 'to Site' no delay
19	1	X	X			X		X	2	4	
20	1	X				X		X	1	4~5	Last 5 sys. Always 'to Site'; try delay in the beginning, once $COF went up and the sequence was not good, test couple of systems
21	1	X	X	X	X	X		X	1	2	No failure during game; in the middle of game I was more willing to pay for delay
5	2	X					X				site(first)-delay 3 sys. test 1 sys.(delay cost high and didn't help)-site(if fail test more)
9	2	X	X		X		X				
2	3	X			X		X				if failed 2 then test more
3	3	X									if fail couple of system, at that point delay was regarded as useful
6	3	X	X	X	X		X				delay couple of sys. Then sent rest of them to site when risk is acceptance
7	3	X		X		X					Few gamble in the middle of the game
11	3	X		X	X	X		X			rotatedly decide 'to Test' or 'Delay' in the beginning since $COF lower
12	3	X					X				delay(if $COF<5 in the beginning), then Site
13	3	X	X	X	X	X	X				
14	3	X						X			

Note: Considering Parts: lists the parts subjects considered when they made decisions in Rigid Game
Sys. On Site: Subjects considered number of systems installed on site and the distribution of site
Sys. On Board: Subjects considered systems leaving dock, the number is known but has not installed on site
p(fail): subjects stated that they calculate the probability of failure to help their decision
Cost of Installation Path: Subjects considered the difference cost of three installation paths
$COF=0: COF: Cost of Flexibility; Subjects claimed that they would definitely delay decision if $COF is zero
$COF increase? : Subjects concerned that cost of flexiblity would increase(decrease) based on delay decision
$COF vs. $fail or $test: Subjects compared cost of flexiblity with Cost of install failure system or Cost of install testing sytsem
Sites? Column: how often subjects sent a system to site when it might fail to install? 1: never; 2: rarely; 3: sometimes; 4: often; 5: always
Beginning of the Game: the first eight weeks of the game
End of the Game: the later eight weeks of the game

These characterizing actions of subject's in the Rigid Game and Flexible Game were used to differentiate policies of different levels of risk-aversion subjects as described in Model Use section.

5.2. Simulation Results

5.2.1. Model Structure

A system dynamics based simulation model of the Rig Installation Game was developed. The model consists of three main subsystems: Installation Subsystem, Strategy Subsystem and Cost Subsystem. Installation Subsystem includes the exact same game board as the one in the experiment, random sequence of systems arriving at the dock, system installation path, and system interface constraints. Strategy Subsystem represents the policies subjects used in either the Rigid Games or the Flexible Games. Decisions made in Strategy Subsystem decide the system installation path which is part of the Installation Subsystem. System installation paths decide the cost of each system (Cost Subsystem). For example, if the decision from Strategy Subsystem of the system leaving fabrication is 'to Test', the system installation path is testing the system in the Installation Subsystem. The cost for the system installation will be $20,000 according to the installation path. Cost Subsystem is the criteria to measure the efficiency and effectiveness of policy performance. Lower cost means better performance. The relationship between subsystems is shown in Figure 7.

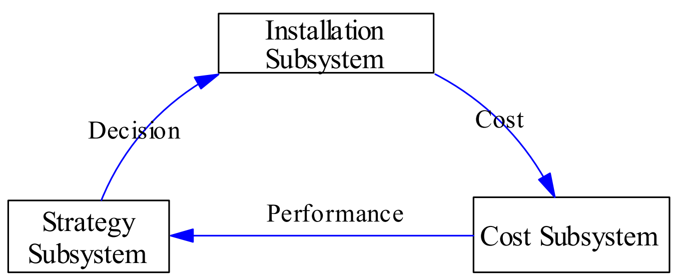


Figure 7 Simulation Model Subsystems

5.2.1.1. Installation Subsystem

The game board in the Installation Subsystem is shown as Figure 8 exactly the same as the experiment game board. An array was used to represent 16 systems in the model. 'Sys. Leaving Fab. Sequence' is decided in the Sequence of System Leaving

Fabrication part as discussed later. Time Steps decides the sequence of operation steps taken in each week as discussed later in the Operation Time Steps part. Decisions ‘Testing System at Dock?’ and ‘Delay System Decision leaving Fabrication?’ are decided in Strategy Subsystem (1 means Yes, 0 means No). ‘Interface Constraints Met Flag’ is the variable that determines whether the system interface constraint of the system is met or not. An example of system 1 interface constraints is:

IF THEN ELSE(Project Site[s2]=1:OR:Project Site[s5]=1:OR:VMAX(Project Site[Sys!]) =0,1,0)

Which means if either systems 2 or system 5 is installed on the site or no system is installed on the site then system interface constraints are met (1), otherwise they are not met (0).

The random Sequence of system leaving fabrication is generated randomly by the computer by changing ‘System Transport Order Seed’ as in Figure 9. ‘Start System Transportation’ is an operation step in Installation Subsystem as shown in Figure 8. The user can also input specific random sequences into the model as desired. This was used to test the simulation model for consistency with specific games as played by subjects in the experiment.

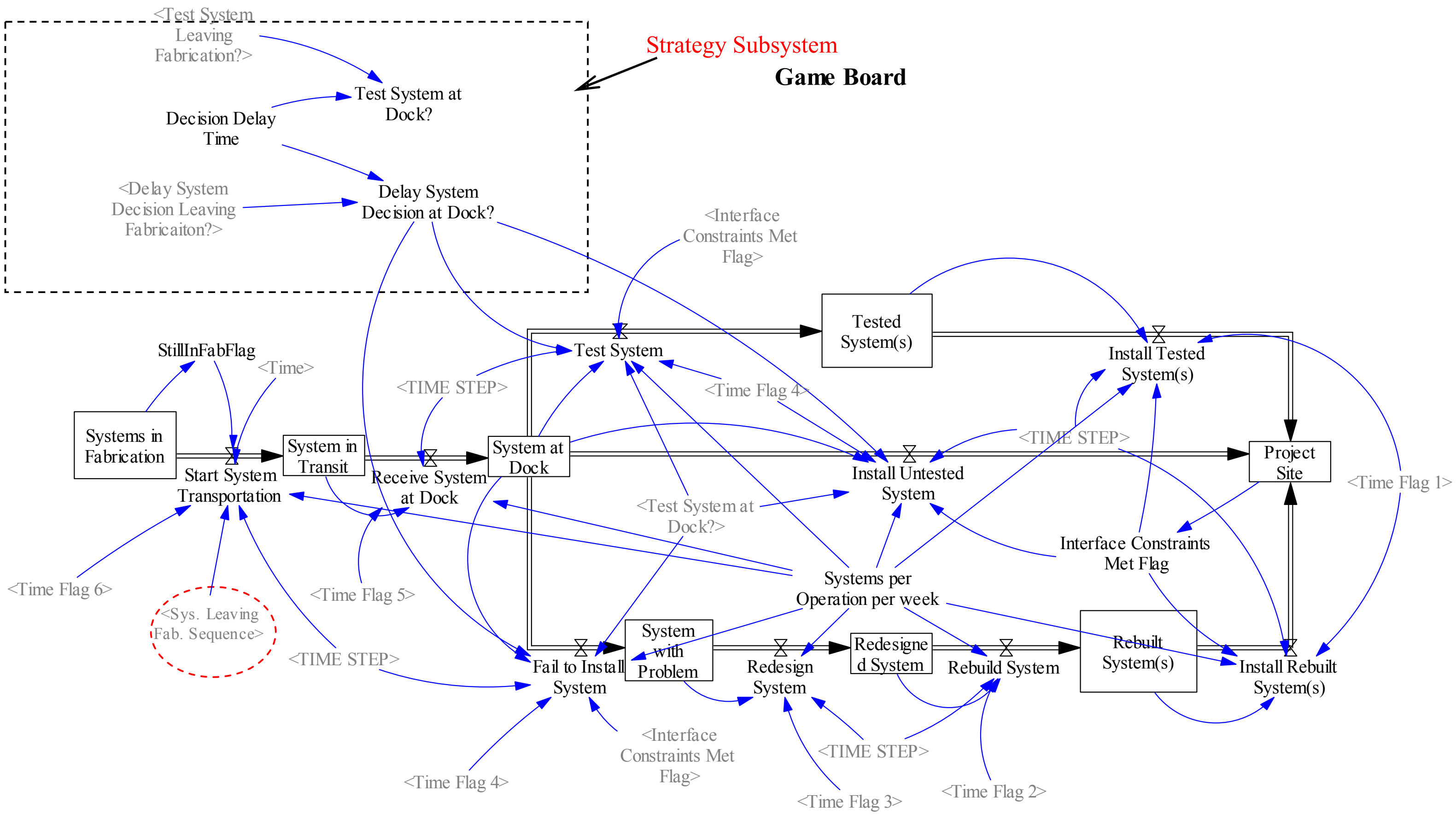


Figure 8 Installation Game Board

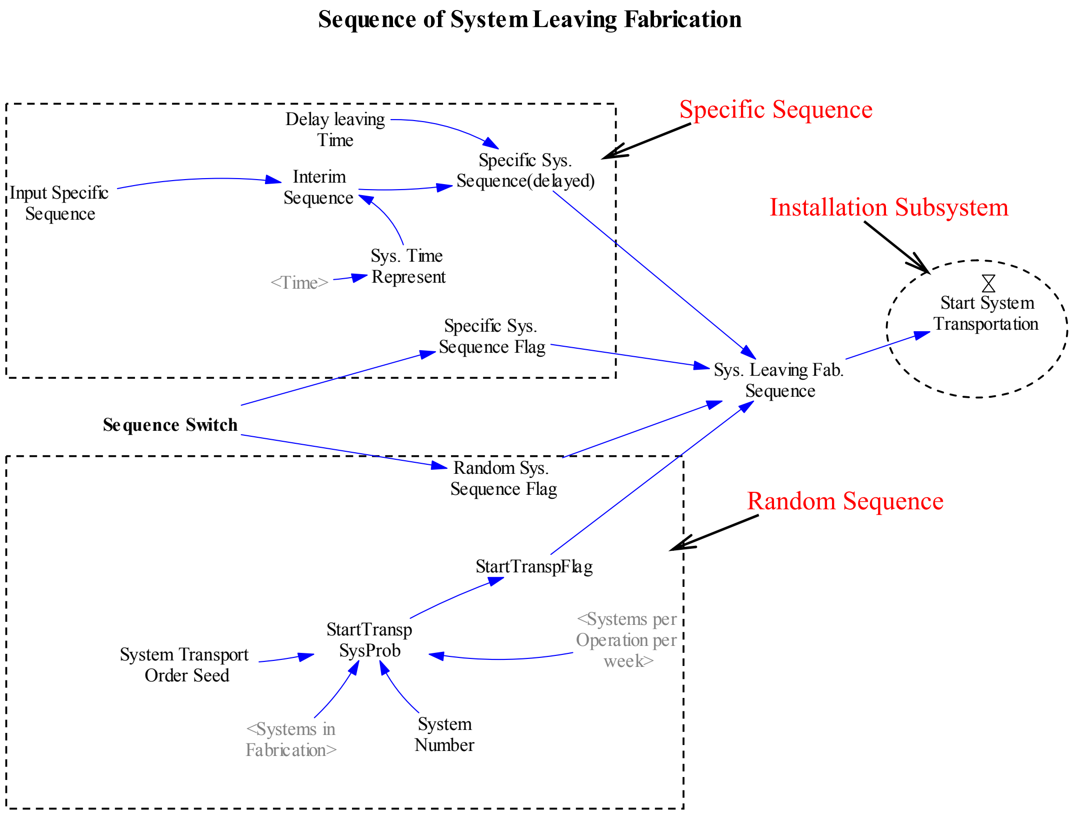


Figure 9 Sequence of System Leaving Fabrication

In the model, the system installation path is decided by a subject's strategy and by the ability of the system to meet system interface constraints. Each week one system leaves fabrication and several steps are taken in sequence as discussed in Appendix A. In the model, 'Whole Time Units' =1 [week], and it was divided into 16 equal time lock steps as follows to enable each operation step in Installation Subsystem to act in sequence as shown in Figure 10.

Operation steps taken each week:

1. Install Tested and Install Rebuilt Systems
2. Rebuild Systems
3. Redesign Systems
4. Ship system at dock to *Yard* or *Site*
5. Receive System at Dock
6. Start System Transport

Time Flag 1 corresponds to the time for operation step 1 taken in each week: Install Tested and Rebuilt Systems, which is carried out as many cycles as possible, until all systems that meet the interface constraints have been installed. It uses first 11 time steps of each week because 10 time steps is the maximum time steps needed is specific sequence of system leaving fabrication happens.

Time Flag 2 corresponds to time for operation step 2 taken in each week: Rebuild System, which is taken right after operation step 1.

Time Flag 3 corresponds to time for operation step 3 taken in each week: Redesign System, which is taken right after operation step 2.

Time Flag 4 corresponds to time for operation step 4 taken in each week: Report previous "to Test/Site" decision and Ship system at dock to Yard/Site, which is taken right after operation step 3.

Time Flag 5 corresponds to time for operation step 5 taken in each week: Receive System at Dock, which is taken right after step 4.

Time Flag 6 corresponds to time for operation step 6 (last step) taken in each week: Start System Transportation (last activity in each week), which is the operation step right after operation step 5.

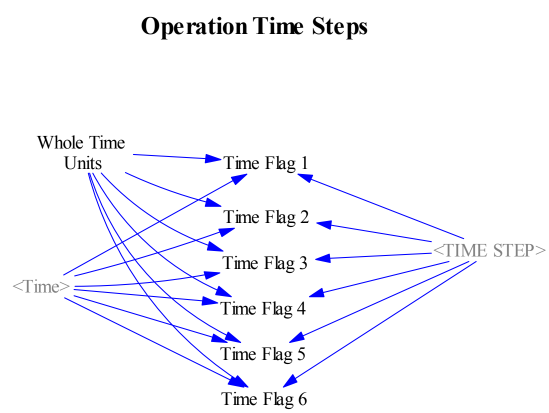


Figure 10 Operation Time Steps

5.2.1.2. Strategy Subsystem

The Strategy Subsystem includes policies used in the Rigid Game and policies used in the Flexible Game. Rigid Game policies include some extreme policies and the Subjects' Rigid Game Best policy. Policy in Rigid Game decides "Test System Leaving Fabrication?" which decides the Installation Subsystem.

Extreme policies in the Rigid Game include:

1) All-Guts Strategy: the subject sends all systems directly to site without testing and is an extremely Risk-seeking strategy
2) All-Test Strategy: the subjects test all systems.
3) Random Strategy: the subject decides either to test or send the system directly to site randomly.
4) Risk-averse strategy: the subject tests all systems unless the system is guaranteed can be installed. In other words, systems never fail to be installed in risk-averse strategy.
5) Subjects' Rigid Game Best policy from experiment results in the Rigid Game was built into the model and discussed in the Model Use section.

The Risk-averse Strategy was generated into the Risk-averse – X Strategy to allow the modeling a wide range of risk-aversion. Risk-averse – X Strategy means the subject tests all systems unless only X systems might fail to be installed. When X=0, it is the same as Risk-averse strategy. When X=13, the Risk-averse – X Strategy is the same as the All-Guts Strategy. Since the first system and the last two systems leaving fabrication can always be successfully installed according to the system interface constraints. That is, when X=13 all system will be sent to site without testing (All-Guts Strategy).

Risk-averse – X strategy is shown in Figure 11. The first system and the last two systems leaving fabrication can always be successfully installed according to the system interface constraints. "Sys. on Board & Installable Sys." is the sum of systems on board and systems with constraints met but have not left the dock. "Time Constraints" means until the first system be installed, the judgment of guaranteed not to fail installation is active because all systems' interface constraints are met before the first system is installed. But in reality, the second and third system leaving fabrication is not guaranteed to be successfully installed.

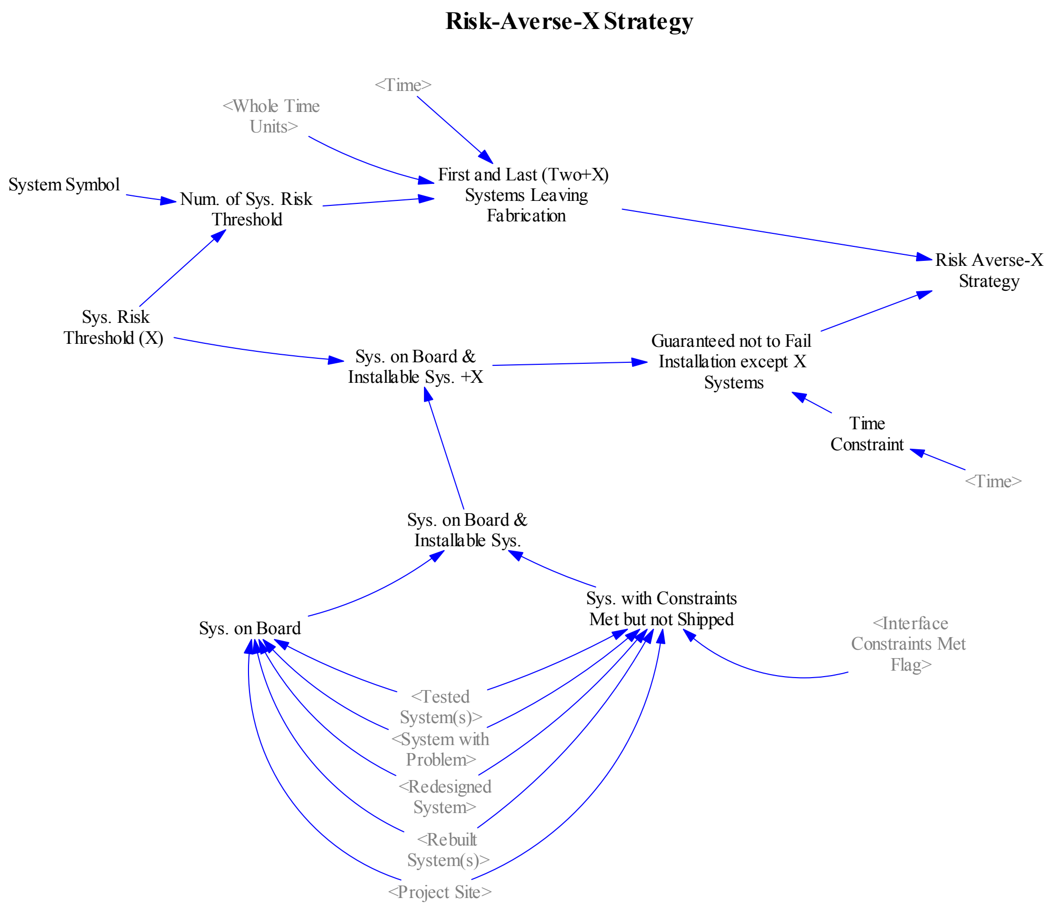


Figure 11 Risk-averse – X Strategy

All the extreme policies mentioned above are used to test the model and provide a performance base case, which is discussed in detail in the Model Validation section. The user can also input his decision for each system to test the model reproduction. Other extreme strategies such as Project Site Condition strategy used to test the model and performance analysis are also built into the model. For details of the model and equations of other Rigid Game Policies refer to Appendix J.1.

Flexible Game policies include the four Rigid Game extreme strategies described above and also include some extreme policies and Subjects' Flexible Game Best policy. Flexible Game Switch is the variable used in the model to switch the game between Rigid Game and Flexible Game. Flexible Game is the combination of delay decisions with the Rigid Game part. The Rigid Game part is used to decide the decision of 'to Site' or 'to Test' if the decision is not Delayed. When the Flexible Game is played, both the delay decision part and the Rigid Game part are working together. When the Rigid Game is played, delay decision part is off. Cost of flexibility is also included in the Flexible Game Policy part. Extreme Flexible Game policies as shown in Figure 12 include:

1) All systems with delay decision: all system decisions are delayed.
2) All uncertainty systems with delay decision: all system decisions are delayed unless the system is guaranteed to be installed.
3) Subject's Flexible Game Best policy: policies from the experiment results were built into the model and discussed in detail in the Model Use section.

Policy in Flexible Game decides "Delay System Decision Leaving Fabrication" which decides the Installation Subsystem. 'Typical Rigid Game Strategy Flag' is the strategy that the user can input his decision for each system to test the model reproduction.

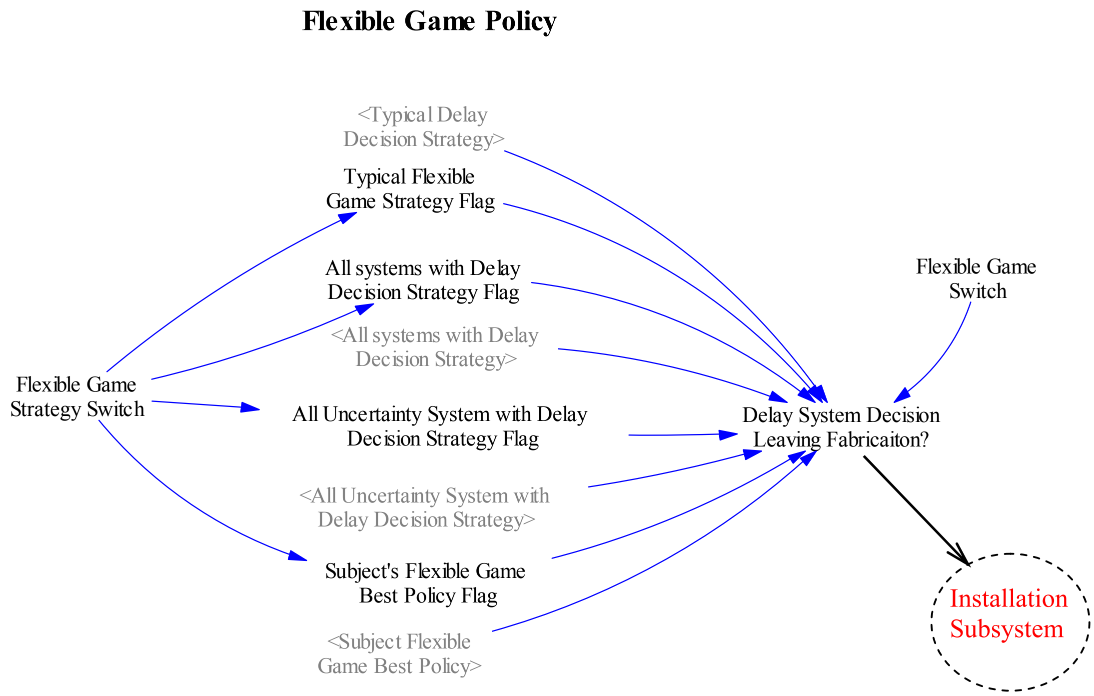


Figure 12 Flexible Game Policy Switch

5.2.1.3. Cost Subsystem

Total cost includes the cumulative operation cost and the total cost of flexibility. Performance is measured by the total cost. The lowest total cost would indicate the best performance. Simulations handled a range of uncertain conditions by changing the System Transport Order Seed. A performance probability density function (pdf) graph was used to test the model and compare policies. This is discussed in details in the Model Validation and the Model Use and Results sections.

There is no flexibility offered for the first system leaving fabrication because it is guaranteed to be installed directly. Cost of flexibility starts with 'Initial Unit Flex. Cost' =$2,000 and it will increase $1,000 for the next system leaving fabrication if the decision for the current system leaving fabrication is delayed otherwise it will decrease $1,000 with a minimum of $0. The cumulative cost of flexibility is 'Total Cost of Flexibility' in Figure 13.

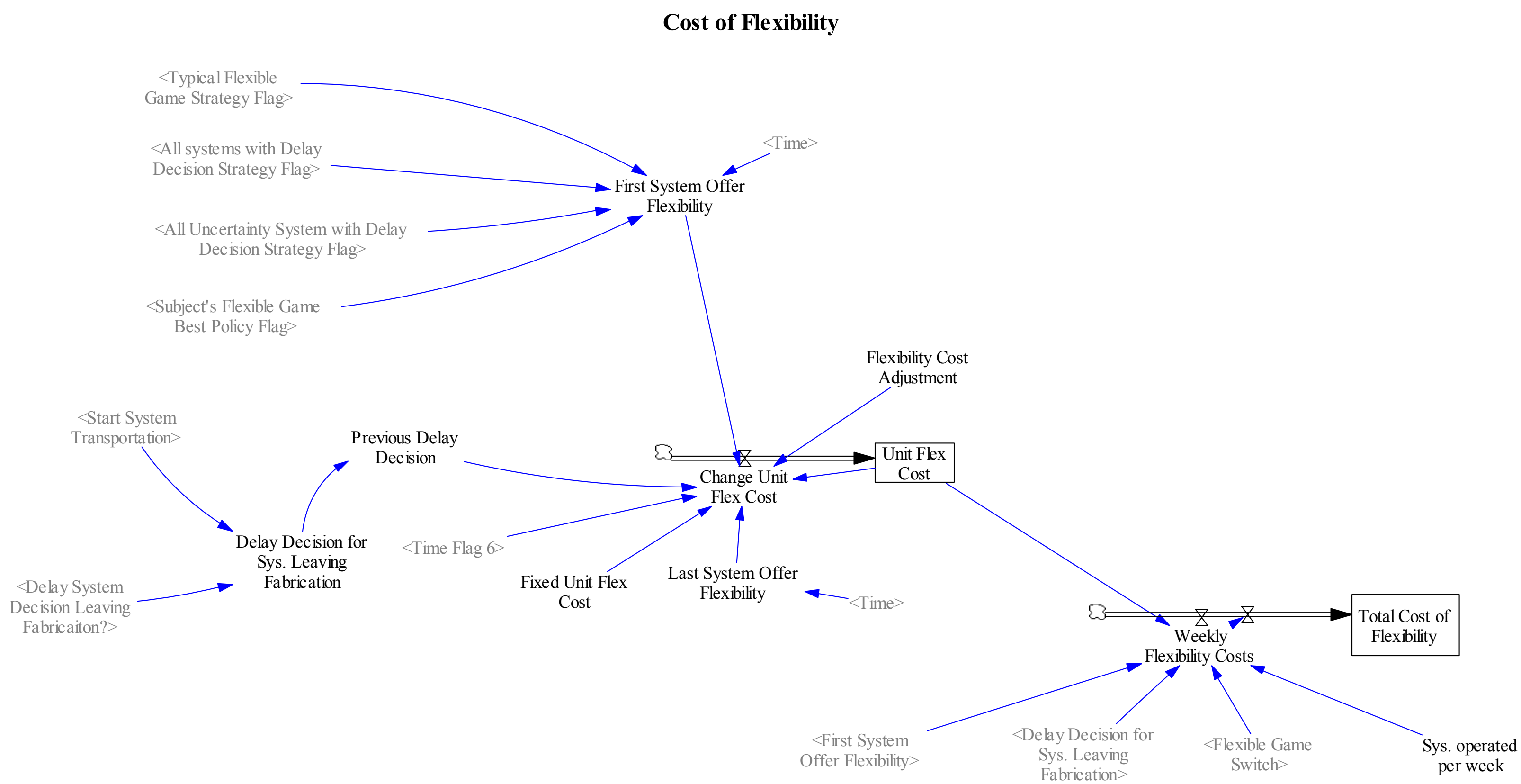


Figure 13 Cost of Flexibility

Total Cost includes Operations Cost and Flexibility Cost. Operation Cost is the cumulative cost of each week, as shown in Figure 14.

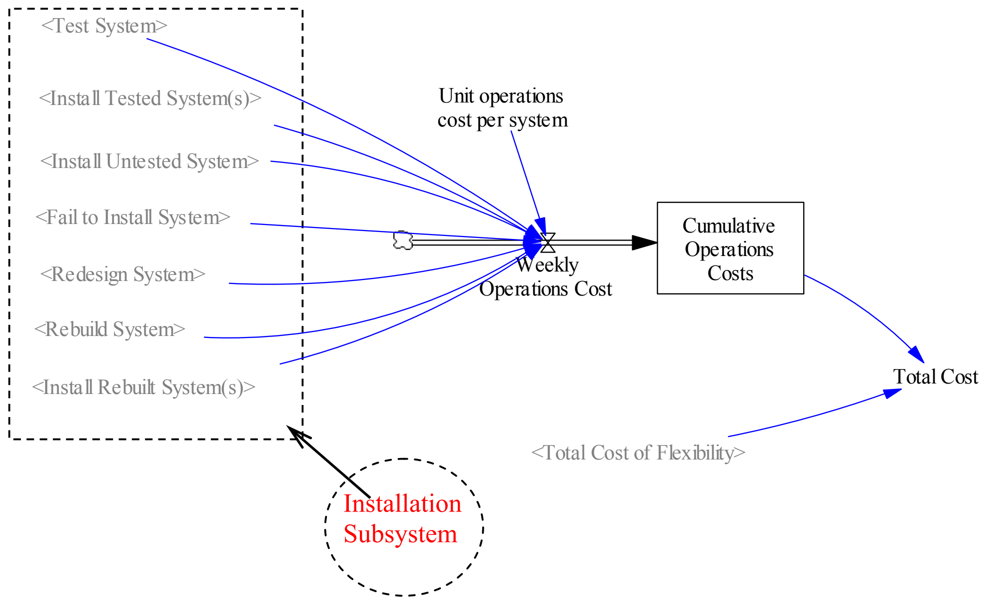


Figure 14 Cost Subsystem

5.2.2. Model Validation and Behavior

Models can be tested by different ways as mentioned in Sterman (2000). To test the overall suitability of the model three tests are used: Structure Assessment Test, Extreme Condition Test and Behavior Reproduction Test were carried out in this research. Structure Assessment tests the consistency of the model with knowledge of the real system and each variable in the model has real meaning. Extreme Conditions tests model behavior in extreme conditions. Behavior Reproductions tests a model's ability to reproduce the real system behavior (Sterman, 2000).

5.2.2.1. Structure Assessment Test

Because the model represents the Rig Installation Game, variables in the model should reflect the game played by subjects. All variables used in the model correspondent to variables in the experiment and real world meaning. For example, variables used to represent a subject's decision should have real meaning in the reality that subjects considered when they made decisions. On the other side, all variables in the experiment can be found in the simulation model.

As described in the Model Structure section, the model has three subsystems. Each of the subsystem corresponds to part of the experiment, as shown in Table 13. Other variables in the bottom of the table are the variables that connect subsystems.

5.2.2.2. Extreme Condition Test

Extreme Conditions Tests include testing the total cost range of the Rigid Game and the Flexible Game with extreme policies. Extreme policies in the Rigid Game part were used to test Strategy Subsystem Rigid Game Policy part. Performance ranges of extreme rigid strategies were calculated based on the game rules. For example, in All-Guts Strategy, all systems were sent to site without testing. If all systems were successfully installed, which was possible when the sequence of systems arriving at the dock were each adjacent to a previously installed system on the project site, then the total cost could be $160,000. Each of the 16 systems only cost $10,000. But if the sequence of systems arriving at the dock was not adjacent to a previously installed system, then a maximum 13 systems would fail. Therefore, the highest cost of the All-Guts strategy would be $550,000, which includes three systems successfully installed at a cost of $10,000 each, 13 systems failed at a cost of $40,000 each. Similarly, the performance range of the All-Test Strategy is $320,000, Random Strategy is $160,000-$550,000 and Risk-averse Strategy is $230,000-$290,000. For details of calculations refer to Appendix K.

Table 13 Experiment Components Versus Model Variables

Subsystem		Experiment	Model	Notes	Details Refer to …
Installation Subsystem		Game Board (three installation paths)	Game Board Variables (three installation paths)	Example: System in Fabrication, System in Transit	Figure 1 and Figure 8 Installation Game Board
		Steps Taken Each Week	Time Step 1,Time Step 2… Time Step 6	Each time step represents each operation step in the experiment	Figure 10: Operation Time Steps
		Random Sequence of System Arriving at the Dock	Sys. Leaving Fab. Sequence	squence could be either Random as in the experiment or Specific Sequence as input by the user in the model	Figure 9: Sequence of System Leaving Fabrication
		System Interface Constraints	Interface Constraints Met Flag	1 means constraints met, 0 meants not	Figure 8: Installation Game Board
Strategy Subsystem	*Rigid Game*	Subject's Rigid Game Policy	Extreme Policies(All-Guts, All-Test, Risk-Averse-X Strategy and Subject's Best Rigid Game Policy	Extreme Policies are used to test model extreme conditions, Subject's Best Rigid Game Policy reflects the results from experiment	Figure 11 and Appendix J.1: Rigid Game Policy
	Flexible Game	Subject's Flexible Game Policy	Extreme Policies in Flexible Game,	Extreme Policies are used to test model extreme conditions, Subject's Best Flexible Game Policy reflects the results from experiment	Figure 12: Flexible Game Policy
		Cost of Flexibility	Cost of Flexibility Part	Same rules of cost of flexibility is applied in the model as discribed in the experiment	
Total Cost Subsystem		Total Cost	Cumulative Operations Costs	All operations cost in the game	Figure 13: Cost of Flexibility and Figure 14:Cost Subsystem
			Total cost of flexibility		
Other Variables		Decision	Test system in Fabrication?	The variable connects Strategy Subsystem with Installation Subsystem	
		Costs	Weekly Operations Cost	The variable counts all the operations cost in each week. It connects Installation Subsystem with Total Cost Subsystem	

Sensitivity analysis of performance was performed by changing the random seed which generated a random sequence of systems arriving at the dock. Performance pdf graphs of 200 simulations for extreme rigid strategies (except 400 simulations of random strategy) are shown in Figure 15. Table 14 summarizes simulation results and expected performance by analysis. In random strategy, simulation results of performance ranges from $220,000 to $490,000 which is narrower than expected. The reason is the very low probability that the total cost will be $160,000, which requires all the decisions to be "to site" and the sequence of systems arriving at the dock adjacent on the project site. Similarly to get $550,000 results requires a very large number of simulations. The consistency of performance between simulations and expectation validated the Strategy Subsystem Rigid Game Policy part.

Performance pdf for the All-Guts strategy and the Random strategy are skewed to the right which is consistent with the experiment design, because the cost of the three system installation paths is skewed to the right. It costs $40,000 for a system installation if the system failed to directly install, $20,000 to test the system and $10,000 for a successful installation.

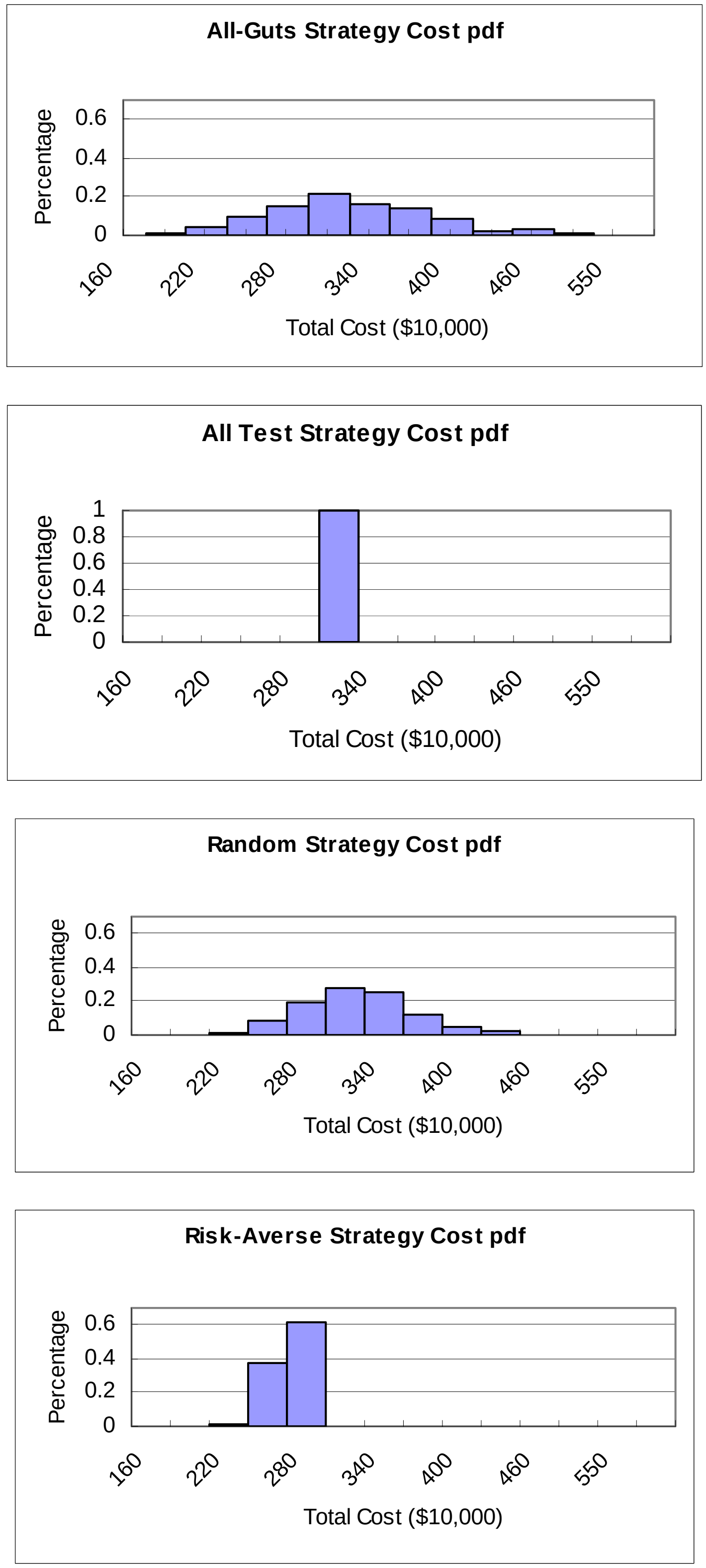


Figure 15 Simulation Performance of Extreme Rigid Policies

Table 14 Simulation Rigid Game Performance With Extreme Policy

Strategy	Mean	Median	Std. Dev.	Skewness	Simulated Min.	Simulated Max.	Simulated Range	Min. by Analysis	Max. by Analysis	Range by Analysis
All-Guts	326	310	64.8	0.56	160	550	390	160	550	390
All-Tests	320	320	0.0	0.00	320	320	0	320	320	0
Random	323	320	43.4	0.34	220	490	250	160	550	390
Risk-Averse	268	270	12.0	-0.35	230	290	60	230	290	60

Unit: $1,000

A performance pdf of Risk-averse – X strategy in Rigid Game is shown in Figure 16. The average cost of installation reaches a minimum when X is three ($253,000) or four ($254,000). But variance increases as X increases. For details of total cost refer to Appendix L. The results indicate that extreme Risk-averse (X=0) strategy does not result in the best performance, but has lowest variance in performance. Taking a certain amount of risk in a Rigid Game such as X=3, X=4 can result in the best performance, with a medium variance.

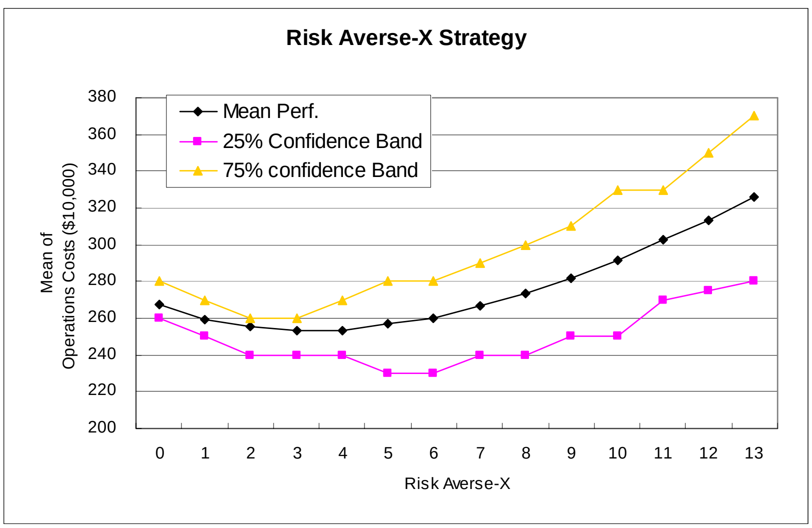


Figure 16 Simulation Performance of Risk-averse – X Strategy

5.2.2.3. Behavior Reproduction Test

Because the model represents the installation game, the behavior of the model behavior should accurately reflect subjects' performance. Real games data and extreme policies are used to test the model behavior reproduction.

Rigid Games played by subjects were used to test the model. A specific sequence of systems arriving at the dock and decisions for each system were input exactly as the real Rigid Games. The same system installation paths and performance as executed in the real experiment game validated the model.

Flexible Games played by subjects were used to mainly test the Delay Decision part and Cost of Flexibility part. The specific sequence of systems arriving at the dock and decisions for each system were input exactly as they were made in the real game. The same system installation path, total cost for cumulative operation costs and total cost of flexibility validated the model.

Through model tests as described above, the model was overall suitable for our research. The model is used for other research analysis as described in the Model Use and Results section.

5.2.3. Model Use and Results

Rigid Game and Flexible Game quantified policies as discussed in Quantified Policies section were built into the model to test and compare policies effectiveness.

In the Rigid Game, subjects mainly considered the p(f) for the system leaving fabrication to make the decision and different levels of risk-aversion have different levels of risk acceptance range, as discussed in the Quantified Policies section. Therefore, in the model, Subjects' Rigid Game Best Policy was modeled as:

> **If** p(successful) > Site Decision Attractiveness Threshold
>
> **Then** Decision for the next system leaving fabrication is *'to Site'*
>
> **Else** Decision for the next system leaving fabrication is *'to Test'*

Different Site Decision Attractiveness Threshold values were used for different levels of risk-aversion to simulate different policies of levels of risk-aversion as shown in Table 15. For details of model refer to Appendix J. 1.iii.

Table 15 Site Decision Attractiveness Threshold Value

Risk-aversion Level	**Site Decision Attractiveness Threshold**
Risk-averse	High [0.7~0.9]
Risk-neutral	Medium [0.4~0.6]
Risk-seeking	Low [0.1~0.3]

Rigid Game average performances as threshold increases from 0.1 to 0.9 with 0.1 increments are shown in Table 16 and Figure 17. Each mean performance is the average performance of 200 simulations (same variables setting the except sequence of systems leaving fabrication is different). Risk-neutral has the lowest average total cost (best performance) among levels of risk-aversion. Risk-seeking has highest average total cost (worst performance) and largest variance among levels of risk-aversion. Risk-averse has medium average total cost but has smallest variance among levels of risk-aversion. All F-test and one-sided t-tests results are statistically significant.

Table 16 Simulation Rigid Game Average Performance of Levels of Risk-aversion

Strategy	Risk-averse	Risk-neutral	Risk-seeking
Site Decision Attractiveness Threshold	0.7~0.9	0.4~0.6	0.1~0.3
Mean Performance	262	253	282
Standard Deviation	15.23	22.00	50.82
Skewness	-0.33	0.20	0.81

p-value for F-test	Risk-averse	Risk-neutral	Risk-seeking
Risk-averse	---		
Risk-neutral	0	---	
Risk-seeking	0	1.81E-84	---

p-value for t-tests	Risk-averse	Risk-neutral	Risk-seeking
Risk-averse	---		
Risk-neutral	8.07998E-14	---	
Risk-seeking	6.58E-21	1.13E-34	---

Unit: $1,000 for Mean Performance

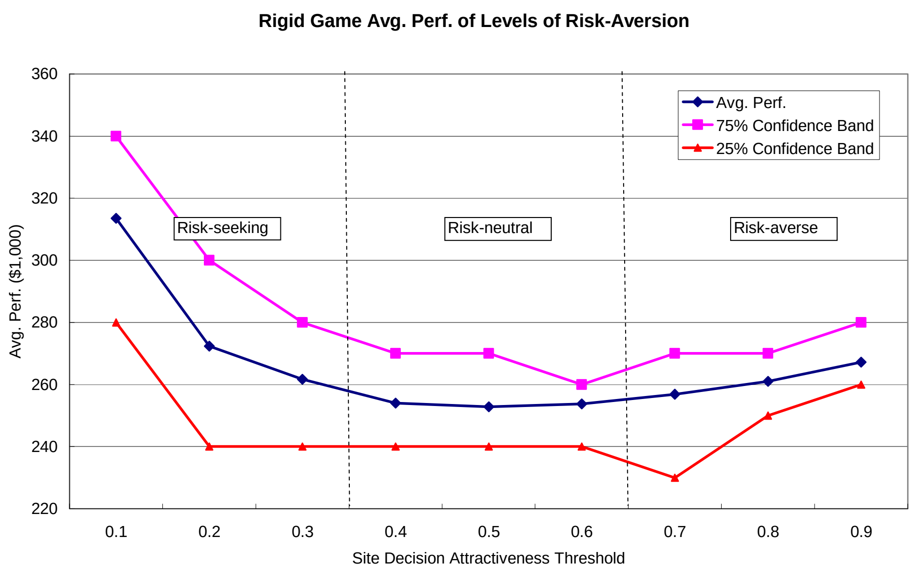


Figure 17 Simulated Rigid Game Average Performance of Levels of Risk-aversion

In the Flexible Game, subjects mainly considered cost of flexibility and the p(f) of the systems leaving fabrication. Risk-averse level subjects' primary concern is the certainty, while risk-seeking level subjects' primary concern is the cost of flexibility. Therefore, in the model, Flexible Game policy was modeled as shown in Figure 18.

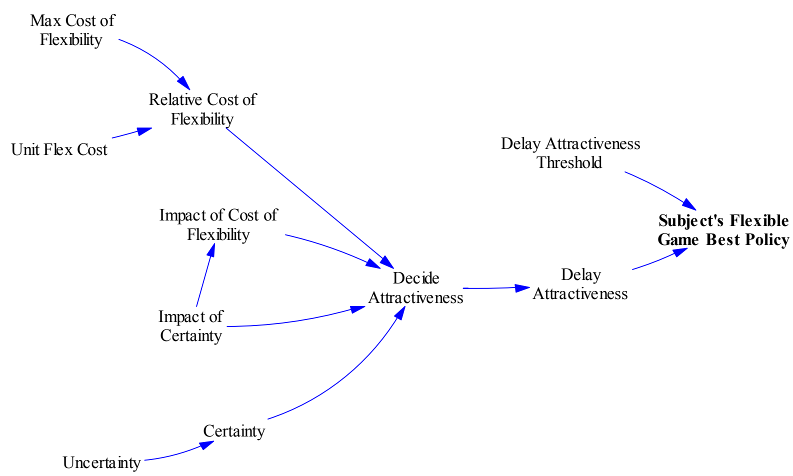


Figure 18 Subject's Flexible Game Policy Simulation

If Delay Attractiveness> Delay Attractiveness Threshold

Then Decision for next system leaving fabrication is *Delayed*

Else *Decide Now*

Equations:

Delay Attractiveness = 1- Decide Attractiveness;

Decide Attractiveness = [0, 1];

Decide Attractiveness = Certainty * Impact of Certainty + Relative Cost of Flex. * (Impact of Cost of Flexibility);

Impact of Cost of Flexibility = 1 – Impact of Certainty;

Impact of Certainty = [0,1];

Certainty = 1- Uncertainty;

Certainty = [0, 1];

Relative Cost of Flex. = Unit Flex Cost / Max. Cost of Flex.

Exception: when Cost of Flexibility = \$0, *Delay Decision*;

when Certainty = 1, *Decide Now*.

Different Impact of Certainty values were used to simulate Flexible Game policies for different levels of risk-aversion as shown in Table 17.

Table 17 Impact of Certainty of Levels of Risk-aversion in Simulation Model

Risk-aversion Level	**Impact of Certainty**
Risk-averse	0.7~0.9
Risk-neutral	0.4~0.6
Risk-seeking	0.1~0.3

Results of simulation as the value of Impact of Certainty increases from 0.1 to 0.9 with 0.1 increments are shown in Table 18 and Figure 19. Each average performance is the average performance of 200 simulations (same variable settings except the sequence of systems leaving fabrication is different). Risk-averse has the lowest average total cost (best performance), while risk-seeking has highest average total cost (worst performance) according to the simulation results. All results are statistically significant.

Table 18 Simulation Flexible Game Average Performance of Levels of Risk-aversion

Strategy	Risk-averse	Risk-neutral	Risk-seeking
Impact of Certainty	0.7~0.9	0.4~0.6	0.1~0.3
Mean Performance	245	258	264
Standard Deviation	17.34	21.50	22.39
Skewness	0.25	0.04	-0.10

p-value for F-test	Risk-averse	Risk-neutral	Risk-seeking
Risk-averse	---		
Risk-neutral	8.63E-08	---	
Risk-seeking	2.65E-10	0.16	---

p-value for t-tests	Risk-averse	Risk-neutral	Risk-seeking
Risk-averse	---		
Risk-neutral	6.69E-30	---	
Risk-seeking	1.92E-59	4.87E-08	---

Unit: \$1,000 for Mean Performance

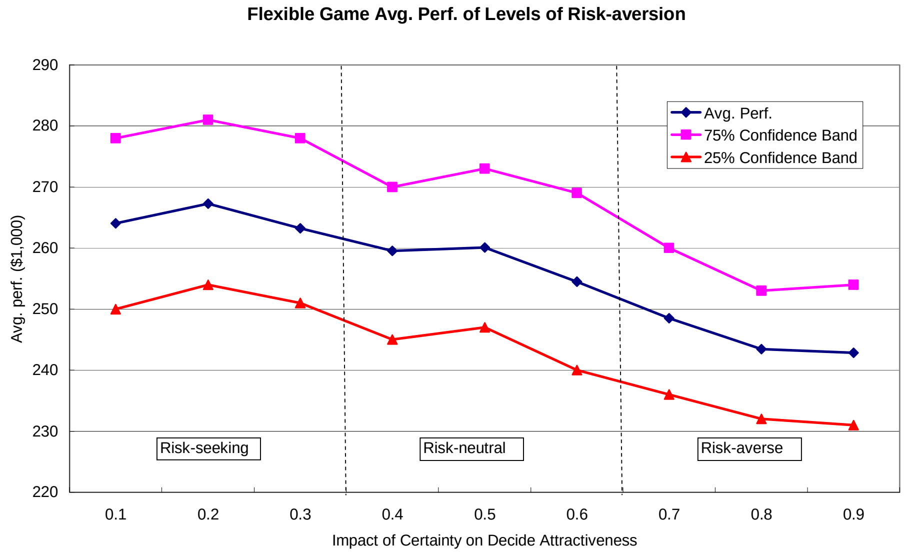


Figure 19 Simulated Flexible Game Average Performance of Levels of Risk-aversion

Simulation performance comparison between Rigid Game and Flexible Game is shown in Table 19 and Figure 20. Average performance on the Flexible Game is statistically better than the average performance on the Rigid Game regardless of risk-aversion levels. The simulation results of performance are consistent with experiment results as described in Hypothesis 1 Test. The simulated total cost of the Rigid Game and Flexible Game is the average of all simulated risk-averse, risk-neutral and risk-seeking in the Rigid Game and Flexible Game performance.

Table 19 Simulation Performance between Rigid Game and Flexible Game

	Risk-seeking	**Risk-averse**	**Total**
Rigid Game	282	262	266
Flexible Game	265	245	256

	Risk-seeking	Risk-averse	Total
p-value for F-test	0	7.44E-04	0
p-value for t-test	1.08E-14	4.55E-63	4.71E-24

Unit: $1,000 for Performance

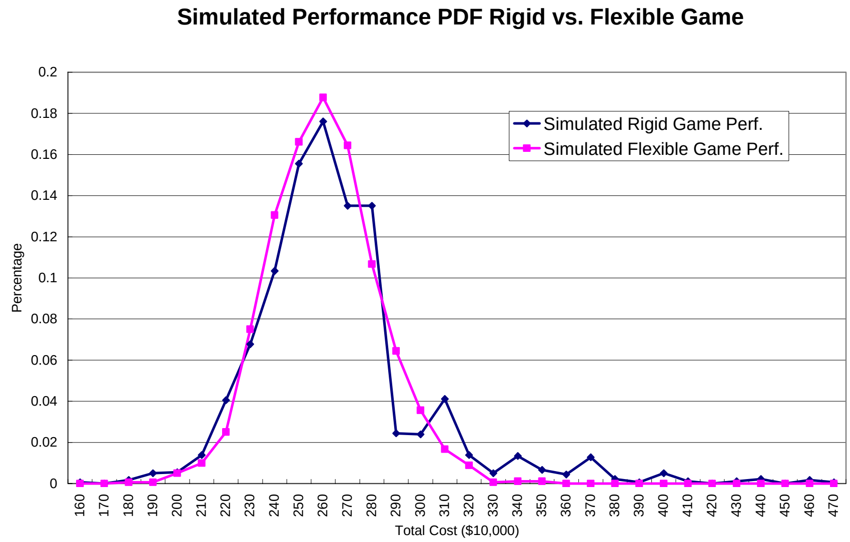


Figure 20 Simulation Performance of Rigid Game vs. Flexible Game

5.3. Performance Comparison

Performance comparison provides insight of policy effectiveness. Average performances of different levels of risk-aversion in the Rigid Game and the Flexible Game, in the Experiment and the Simulation are shown in Table 20. Improvement from Rigid Game to Flexible Game is shown in Table 21. Table 22 shows the p-value of t-tests among different levels of risk-aversion. If p-value is less than 0.05, then the difference between the average performances is significant, otherwise the results is not significant. Therefore, the level of risk-aversion with best performance is summarized in Table 23.

Table 20 Performance Summary

		Experiment Results			Simulation Results		
		Operational Cost	Flexibility Cost	Total Cost	Operational Cost	Flexibility Cost	Total Cost
Rigid Game	Risk-Averse	---	---	263	---	---	262
	Risk-Neutral	---	---	---	---	---	253
	Risk-Seeking	---	---	275	---	---	282
Flexible Game	Risk-Averse	226.8	7.2	234	240.8	4.2	245
	Risk-Neutral	---	---	---	238.8	19.2	258
	Risk-Seeking	243.6	16.4	260	235.9	29.1	265

Unit: $1,000

Table 21 Improvement from Rigid Game to Flexible Game

	Experiment Results				Simulation Results			
	Risk-Averse	Risk-Neutral	Risk-Seeking	Total	Risk-Averse	Risk-Neutral	Risk-Seeking	Total
Rigid Game	263	---	275	270	262	253	282	266
Flexible Game	234	---	260	247	245	258	265	256
Improvement	11.0%	---	5.5%	8.5%	6.5%	-2.0%	6.0%	3.8%

Unit: $1,000

Table 22 T-tests Among Performance

		Experiment Results			Simulation Results		
		Risk-Averse	Risk-Neutral	Risk-Seeking	Risk-Averse	Risk-Neutral	Risk-Seeking
Rigid Game	Risk-Averse	---	---		---		
	Risk-Neutral	---	---	---	8.08E-14	---	
	Risk-Seeking	0.17	---	---	6.58E-21	1.13E-34	---
Flexible Game	Risk-Averse	---	---		---		
	Risk-Neutral	---	---	---	6.69E-30	---	
	Risk-Seeking	0.0002	---	---	1.92E-59	4.87E-08	---

Table 23 Policy With Best Mean Performance

	Experiment Results	**Simulation Results**
Rigid Game	No Significant Difference	Risk-neutral
Flexible Game	Risk-averse	Risk-averse

Simulation results of different levels of risk-aversion in Rigid Game and Flexible Game are shown in Figure 21.

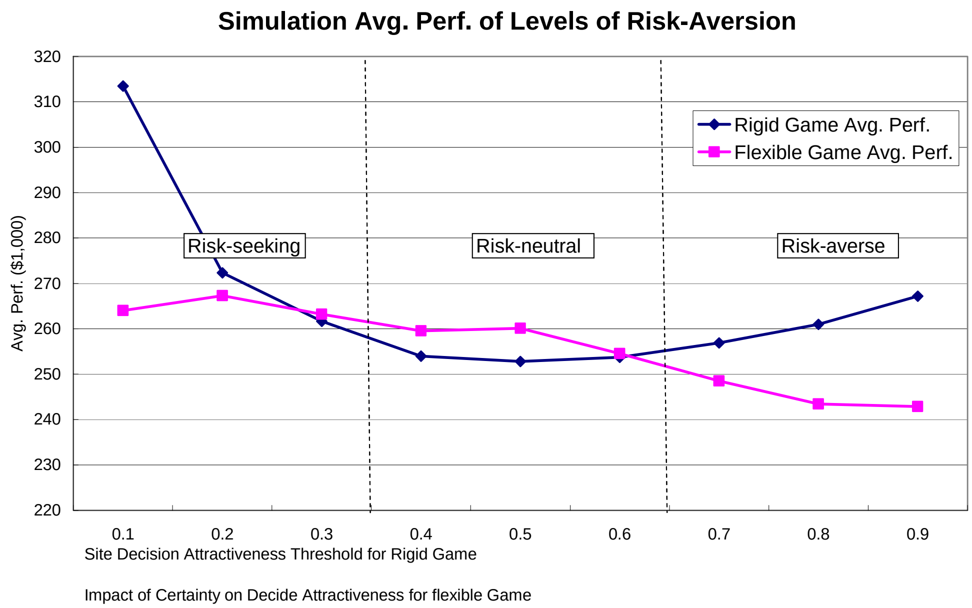


Figure 21 Simulation Average Performance of Levels of Risk-Aversion

From above tables and figures, following results concluded:

1) Using flexibility in uncertain projects to improve project performance.
2) Risk-neutral would perform best in uncertain project without flexibility.
3) Risk-averse would perform best in uncertain project with low cost of flexibility.
4) Uncertain project performance is more robust with flexibility than without flexibility, from the flat simulation performance in Figure 21.

6. CONCLUSION

Understanding how people perceive and value flexibility can provide ideas for improving operational Real option theory, which can help construction managers' understanding and capture the maximum value of flexibility and can reduce the gap between Real option theory and construction managers' practice.

An experiment was used to capture managers' perception of flexibility. Data from 42 Rigid Games and 82 Flexible Games played by 21 subjects were collected and compared. A simulation model was used to test the effectiveness of policies used by subjects. Hypotheses based on Real option theory were tested. Results are laid out as follows.

- Hypothesis 1 (Subjects value flexibility as an effective tool for managing uncertain projects) was supported by experiment results.
- Hypothesis 2 (Subjects' perceived value of flexibility positively correlates with perceived uncertainty) was supported by experiment results.
- Hypothesis 3 (Differences in levels of risk-aversion impact the perceived value of flexibility) was supported by the experiment
- Hypothesis 4 (Value of flexibility in subject's perception is positively correlated with flexibility expiration time) was not supported by experiment results.
- Hypothesis 5 (Value of flexibility in subject's perception is positively correlated with asset value) was supported by experiment results.

6.1. Contributions

This research has objectively measured subjects' perception of real options (flexibility) and tested subjects' understanding of the relationship between value of flexibility and three factors in Real options theory. This research is the first research in real options area known to us to collect data from people in controlled experiments to describe behavior. This research found that subjects have a conceptual understanding of real options (flexibility) and the relationship of option value with uncertainty, which is not known to have been identified by previous research.

6.2. Real Options Theory Implications

We conclude from this research that managers value real options (flexibility) as an effective tool in managing uncertain projects. Managers often are not aware of the six factors in the Black-Schole's equation for valuing a financial option or how they impact on value of flexibility. However, managers correctly identified the positive relationships between value of flexibility and uncertainty and asset value. But, they did not have a clear understanding of how to estimate the maximum value of flexibility and how much each factor would affect the value. There is no support from the experiment that they clearly realize the relationship between value of flexibility and flexibility expiration time. Different levels of risk-aversion impacted the perceived value of flexibility, which is not considered in Real-Option theory.

6.3. Limitations of Research

However, in the experiment, only one uncertainty was considered in the RIG Installation Game: the random sequence of systems leaving fabrication. Real projects involve multiple uncertainties. Subjects made decisions in a short time and individually during the experiment. Calculators, software and other helping tools were not available to help subjects make a decision. According to Bounded Rationality Theory, people are only partly rational, and are emotional/irrational in parts of their decisions making, because there are limits to formulating and processing knowledge to solve complex problems, especially when continuous decisions need to be made (Simon, 1978). The current statistical analysis provided precious data to answer research questions although it might not be significant based only on data collected from 21 subjects. The lack of real world project experience among students was another limit of this experiment.

6.4. Further Research Based on Current Research Results

Based on current research results, the following future research and data analyses would be worth. More data collection from construction managers is desired. Due to a two hours experiment time, experiment computerization may be helpful for further data collection. Once more data are collected, the following data analysis could be carried out:

1) Risk-neutral level subjects' performance and characteristics could be compared with other risk-aversion levels.
2) Data could be compared based on the sequence of games to analyze whether subjects learn (make improvement) from playing. For example, all subjects' first Flexible Games performances are aggregated and compared with all subjects' second Flexible Games performances.
3) Data could be analyzed and Hypotheses could be test based on subjects if more games were played by individual subject.
4) Levels of risk-aversion subjects' experiment Rigid Games performance and decision making characteristics would be analyzed. The results would be compared to construction management theory.
5) Making necessary adjustments, even changes of policies used in Rigid Games and Flexible Games as summarized in the Quantified Policies section based on more collected data. These adjustments/changes could be used to improve the simulation model Strategy Subsystem.

6.5. Future Research of Real Options

Therefore, future research would not focus on convincing managers that real options (flexibility) is an effective tool in managing uncertain projects. Future research needs to focus on developing tools to help managers accurately measure the maximum value of flexibility. Future research needs to focus on improving manager's awareness of the six factors that will impact value of flexibility and improving their understanding of the relationship of these six factors with the value of flexibility. Future research needs to focus on developing tools to help managers measure the six factors impaction on value of flexibility precisely. Future research would consider managers' level of risk-aversion as an important factor in evaluating the value of flexibility. Future research can include the other three flexibility value impacting factors (risk free rate of return, present value of expected cash flow, value lost over duration of option) in experiments and interview a large amount of construction managers instead of students.

6.6. Managerial Implication

Based on this research, construction managers gain beneficial from flexibility as tool in highly uncertain projects. Depending on ranges of flexibility used in projects, construction managers can perform differently based on the levels of risk-aversion they chose. If there is no flexibility used in the uncertain project, then risk-neutral or risk-averse strategy will perform better than using risk-seeking strategy. If there is flexibility used in the uncertain project, then risk-averse strategy will perform better than using risk-neutral or risk-seeking Strategy.

Managerial real options are important to construction management. Improving understanding of managerial real options can improve project performance. Experiment of this research into the behavior of managers can contribute to this knowledge understanding.

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APPENDIX A

THE RIG INSTALLATION GAME[1]

You are a construction manager on an Installation Team for a semi-submersed, deep water exploration and production rig for oil and gas in the Gulf of Mexico. The rig is composed of multiple systems such as the sea floor anchors, support cables, flotation can, topsides, drill rig, etc. The rig's size and complexity require that its systems be assembled and installed on-site. Individual systems are built in different yards by different contractors. To create a competitive advantage these systems are first-of-a-kind or include the latest technology. When each system is completed it starts the journey from its fabrication yard to a dock near Corpus Christi, Texas. The arrival of the systems at the dock is scheduled to occur in an optimal sequence and close to each other in time to meet the team's installation deadline. But the large uncertainties inherent in designing and building innovative systems make perfectly forecasting and controlling the completion sequence of the systems impossible. The actual arrival sequence at the dock often appears closer to being random than optimal. From the dock, each system is either moved into a yard near the dock or shipped directly to the site for installation. In the yard systems are tested for fit with other systems with templates and precision laser locating equipment. The Installation Team refers to these fitting requirements between rig systems as "system interface constraints." Any required changes identified in testing can be made relatively quickly at low cost in the yard. These changes assure successful installation on site when the system interface constraints are met. In contrast, if a system is shipped directly from the dock to the site it is tested for fit by trying to install it. Systems that meet the system interface constraints set by the previously installed systems are installed. But systems that are shipped directly to the site and fail to meet these constraints must be redesigned, then rebuilt on-site, and held until the constraints are met before they can be installed.

Both the dock and the yard are expensive and scarce resources. Therefore the

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[1] . Developed by David Ford, January, 2004.

Installation Team managers must reserve the yard for a system when it leaves the fabrication yard and begins the trip to Corpus Christi and must move each system to the site or yard soon after it reaches the dock. This forces the team to decide whether to test each system in the yard or attempt to install it on-site when it leave the fabrication yard, *before* the team knows if the system will meet the system interface constraints or not.

Each of the seven operations described above (test in yard, install tested systems, successfully install untested systems, fail installation, redesign, rebuild, install rebuilt systems), require an average of a week to complete and cost an average of $10,000 to perform. Therefore, the three possible ways to get a system installed are:

Installation Path	**Operations Cost** (x$1,000)
1. Ship to site & successfully install an untested system ($10)	10
2. Ship to site & fail installation ($10), redesign ($10), rebuild ($10), install a system ($10)	40
3. Test in yard ($10), install a tested system ($10)	20

Given the uncertainties in the arrival sequence of systems at the dock, the installation success of systems shipped directly to the site, and the differences in costs and durations of the three installation paths, how should the Installation Team decide which systems to test and which to ship directly to the site in order to minimize total costs? How much will the installation cost?

System Interface Constraints: System interface constraints are met when installation of the system will create a shared edge with a previously installed system. For Example: If system 5 is the first system installed, then system 1, 6 and 9 can be installed next. If system 13 is the first system installed, then only system 9 and 14 can be installed next.

Operation Notes

1. Each system moves one position (box) toward the project site per week once it left

fabrication. However, more than one system can be installed on site per week as long as this system's interface constraints are met.

2. Shuffle the systems very well after each project.

3. Systems must be installed as soon as they meet the interface constraints. The first system must go to the site and will be successfully installed.

The Installation Game

Steps Taken Each Week

Rigid Game

No.	Action	Operations Cost (x$1,000)
1.	**Install Tested** and **Install Rebuilt Systems**	$10 per system
2.	**Rebuild Systems**	$10
3.	**Redesign Systems**	$10
4.	**Report** previous "To Test", "To Site" commitment of system at dock and…	
	then…**Ship system at dock to Yard or Site**:	
	IF ("Ship system to yard to Test") THEN (**Ship to Yard and test**)	$10
	IF ("Ship system to site") THEN(Attempt installation)	
	IF (Interface constraints met) THEN (Successfully **Install System**)	$10
	IF (Interface constraints not met) THEN (**Fail Installation**)	$10
5.	**Receive System at Dock**	free
6.	**Subject Decision "To Test" or "To Site"** **Record decision**	
7.	**Start System Transport**	free

The Installation Game

Steps Taken Each Week

Flexible Game

No.	Action	Operations Cost (x$1,000)
8.	**Install Tested** and **Install Rebuilt Systems**	$10 per system
9.	**Rebuild Systems**	$10
10.	**Redesign Systems**	$10
11.	**Report** previous "To Test", "To Site", or "Delayed Decision" commitment of system at dock and… If "Delayed Decision" ***SUBJECT CHOOSES*** "to Test" or "to Site" and record, then… **Ship system at dock to Yard or Site**:	
	IF ("Ship system to yard to Test") THEN (**Ship to Yard and test**)	$10
	IF ("Ship system to site") THEN(Attempt installation)	
	IF (Interface constraints met) THEN (Successfully **Install System**)	$10
	IF (Interface constraints not met) THEN (**Fail Installation**)	$10
12.	**Receive System at Dock**	free
13.	Refer to previous Delayed Decision choice and cost. **Determine next Delayed Decision cost for system in fabrication.**	
14.	For system in Fabrication offer "to Test", "To Site" (free) and "Delay Decision" (Cost from Step 6) ***SUBJECT CHOOSES*** and **Record decision and cost offered.**	
15.	**Start System Transport**	free

APPENDIX B

MANAGERIAL PERCEPTIONS OF OPERATIONAL FLEXIBILITY

INTERVIEW QUESTIONS

Describe the guidelines or rules which you *actually* used, not a policy which you believe would perform well or not a policy which you wish in hindsight that you had used. (Based on the performance (investigator's observe) during games to adjust the questions)

Decision Making in Games without Flexibility

- **How did you make Test/Site decisions during Games without Flexibility?**
  - i. Which parts of game did you consider when making decisions?
  - ii. Order of importance (most-to-least) of those parts?
  - iii. How did you use those parts to decide Test or Site?
  - iv. About how often did you send a system directly to Site when installation might fail? [Never, Rarely, Sometimes, Often, Always]
    ---- Beginning of the game & End of game

Decision Making in Flexible Games (Emphasis on Difference)

- **How did you decide whether Delay Decisions or decide to Test/Site when a system left fabrication?**
  - i. Which parts of game did you consider when making Delay/Decide-Now decisions? Differences from games without flexibility?
  - ii. Order of importance (most-to-least) of those parts? Differences from games without flexibility?
  - iii. How did you use those parts to decide? Differences from games without flexibility?
  - iv. When you chose to Site/Test decisions for the system at Fabrication, about how often did you send a system directly to Site when installation

might fail? Differences from games without flexibility? [Never, Rarely, Sometimes, Often, Always]

---- Beginning of game & End of game

Perception of Net Savings of Delaying Test/Site Decisions in Flexible Games

"Delaying decision makes sense if it reduces total cost, i.e. operations savings are larger than delaying Cost."

- **How did you estimate the net savings of delaying the Test/Site decisions?**
  i. If we ran many games will the average total cost with flexible be [same, higher, lower] than without flexibility? Why?
  ii. If you are the person who decides the Cost of Flexibility for each system, what will be the maximum you would like to pay? Why? Does it change during the game from the beginning to the end. [Constant, decrease, increase, other?] Why?

Influence Factors on Net Savings

- **What other aspects do you think affect the amount of net savings? How? Why?**
  i. If you played the Flexible Game again exactly as we just did EXCEPT that each operation cost $5,000 instead of $10,000, so does flexibility cost is half of Previous, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?

  ii. If you played the Flexible Game again exactly as we just did EXCEPT that it takes four weeks instead of two weeks to transport systems from Fabrication to Dock, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?

  iii. If you played the Flexible Game again exactly as we just did EXCEPT systems that would share a corner with a previously installed system can be successfully installed as well as systems that would share a edge, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?

APPENDIX C

EXPERIMENT PROTOCOL

1. Describe research area and interview purpose. Describe general agenda and reward for good performance.
2. Consent Form
   Audio Tape Release Form
3. Demographic Information Questionnaire
4. Read Rig Installation Game Cover Story
   Alternative: Explain the game to the participant
5. Play Rig Installation Games
   a) Rigid Games without flexibility
      i. Play one practice game.
         Rule: First 5 systems must be 'To Site', then participant plays the rest of systems.
         Show Results
      ii. Describe All-Guts Strategy, Random Strategy, All-Test Strategy, Risk-averse Strategy
         Provide performance data (simulation results) (Table C-1, Figure C-1) of these extreme strategies
      iii. Define Subject's Rigid Game Best Strategy
         Two games with Subject's Rigid Game Best Strategy
      iv. Interview about Subject's Rigid Game Best Strategy
   b) Flexible Games

Note: Inform the subject that performance for reward is average of all following games.

      i. Describe Cost of Flexibility.
      ii. (Three ~ Six) games with Subject's Flexible Game Best Strategy
      iii. Interview about Subject's Flexible Game Best Strategy
         Define: Net Saving = Operational Cost Savings – Cost of right to Delay Decision
6. Conclusion and Closing

Table C-1 Simulation Performance with Extreme Rigid Game Policies

Strategy	Mean	Median	Std. Dev.	Skewness	Simulated Min.	Simulated Max.	Simulated Range
All-Guts	326	310	64.8	0.56	160	550	390
All-Tests	320	320	0.0	0.00	320	320	0
Random	323	320	43.4	0.34	220	490	250
Risk-Averse	268	270	12.0	-0.35	230	290	60

Unit: $1,000

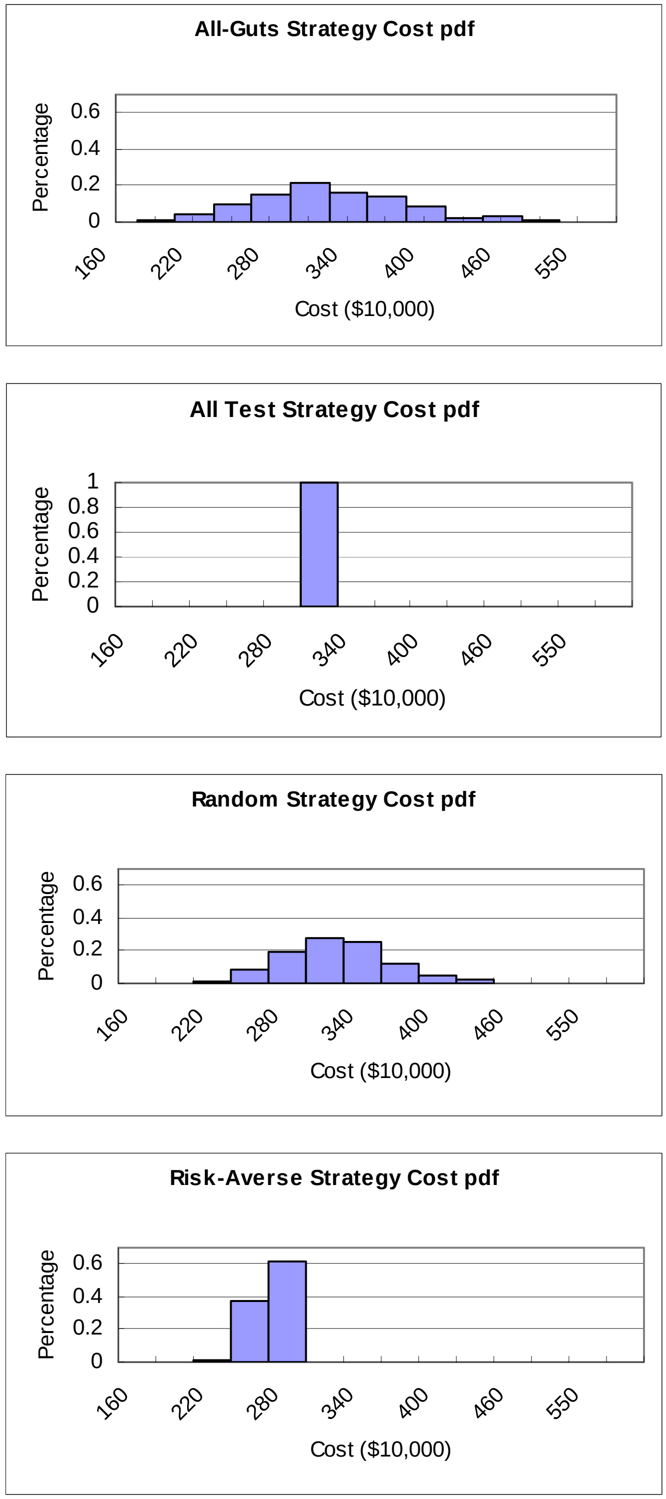

Figure C-1 Simulation Performance with Extreme Rigid Game Policies

APPENDIX D

EXPERIMENT PERFORMANCE

Table D-1 Experiment Performance of 21 Subjects

	Performance										
Participant No.	**Practice Rigid**	**Rigid1**	**Rigid2**	**Avg. of Rigid**	**Flexible 1**	**Flexible 2**	**Flexible 3**	**Flexible 4**	**Flexible 5**	**Flexible 6**	**Avg. of Flex.**
1	280	260	250	255	242	246	232				**240**
2	430	300	270	285	239	308	285	236	246		**263**
3	300	230	320	275	240	314	322	228	227	280	**269**
4	310	320	280	300	213	220	203	257			**223**
5	340	310	240	275	252	331	223				**269**
6	380	230	240	235	243	284	217				**248**
7	250	320	310	315	260	260	271	242			**258**
8	300	250	240	245	241	220	230				**230**
9	270	360	240	300	203	248	247				**233**
10	300	240	260	250	244	235	238				**239**
11	320	320	280	300	220	227	226	241			**229**
12	320	220	340	280	179	287	354	304	321	203	**275**
13	260	220	300	260	305	309	231	231	233	201	**252**
14	260	270	230	250	245	270	265	270	304		**271**
15	360	260	240	250		216	225	216	235	233	**225**
16	380	240	300	270	240	241	223				**235**
17	290	270	210	240	227	209	260				**232**
18	280	240	230	235	201	211	234				**215**
19	230	340	250	295	248	221	251				**240**
20	340	350	260	305	249	263	280				**264**
21	280	240	250	245	221	240	230	245			**234**
	310	278	264	270	236	255	250	247	261	229	**247**

Unit: $1,000

Note: Practice Rigid Column: lists the performance of each participant during the first practice Rigid Game

Participant played one practice Rigid Game, two Rigid Games, and 3~6 Flexible Games

Participant No.15's first Flexible Game results is deleted due to subject's misunderstanding of Flexibility

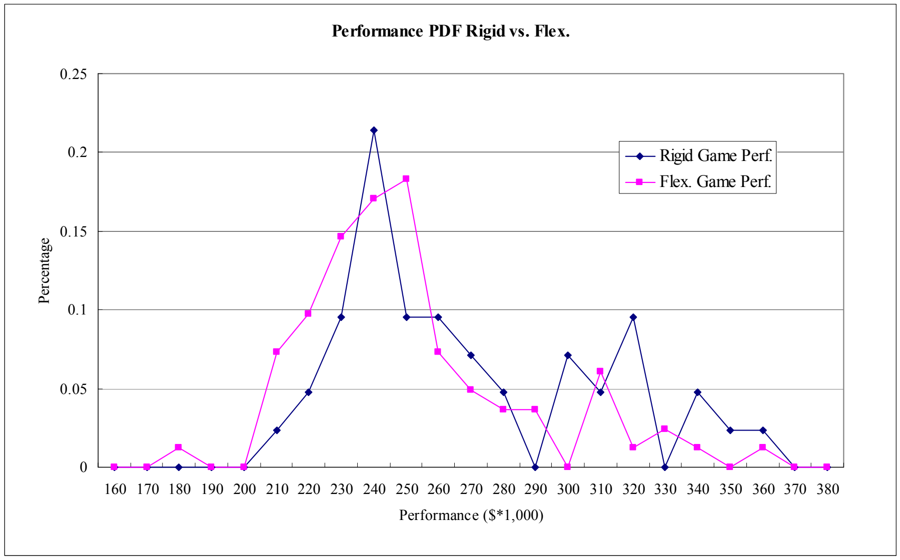

Figure D-1 Experiment Performance pdf of Rigid Game vs. Flexible Game

APPENDIX E

SUBJECT'S PERCEPTION OF PERFORMANCE BETWEEN RIGID GAME AND FLEXIBLE GAME

Interview Questions:

1) If we ran many games will the average total cost with flexible be [same, higher, lower] than without flexibility? Why?

2) If you are the person who decides the Cost of Flexibility for each system, what will be the maximum you would like to pay? Why? Does is change during the game from beginning to the end. [Constant, decrease, increase, other?] Why?

Answers:

Table E-1 Interview Answers A

Participant No.	Avg. Flexible vs. Avg. Rigid	Max $COF participant willing to pay ($1,000)	Reason for Avg. total cost with flexible lower than rigid game
1	Lower	5	No detailed discription
2	Lower	6	No detailed discription
3	Lower	?	Delay decision allow sufficient time to make decision
4	Lower	5	Cost of delay is less than cost to test: I only delay when p(s)>>p(f)), which I test it in rigid game; [when p(s)< p(f), test anyway, no delay]
5	Lower	3	$0 to delay, which give definite picture, max$COF=2, love $0
6	Lower	?	Flex. reduce likelihood of failure in long run
7	Lower	1	$0 delay, reduce overall risk
8	Lower	10	Delay decision allow get more information to make decision
9	Lower	3	More risk in rigid game, $fail is high; Delay prevented fail and $cof is relatively low
10	Lower	3	Delay to avoied fail, which cost relatively less then failure
11	Lower	5	$cof is much less than $fail
12	Lower	5	Delay avoid failure with relatively lower cost compare to $fail
13	Lower	5	$cof is much less then $test
14	Lower	6	Delay provide opportunity to get more infomaiton and know exactly what decision to make
15	Lower	5	$cof is relatively cheap than $test, or $fail
16	Lower	5	$0 to delay increase chance to go to site directly, reduce overall cost
17	Lower	20	$cof is much lower than $fail, 1*$fail=2*$test, then choose many times delay to avoid failure
18	Lower	4	$cof is low, middle of the game would like to pay $1,$2 to delay. $(test-site)*50%=$5
19	Lower	2	Delay decision allow getting more information to make decision
20	Lower	2	Delay avoid failure with relatively lower cost compare to $fail
21	Lower	9	Always avoid failure without having to Test, sometimes to Site with delay. $cof is relatively low cost compare to $test.

Unit: $1,000 for Max $COF

Notes: Max $COF participant willing to pay column: '?' means subject have difficulty answering the question.

$COF: Cost of Flexibility; $fail: Cost of failure which is $40,000 totally for installation the system; $test: Cost of Test system which is $20,000 totally for installation the system.

APPENDIX F

COST OF FLEXIBILITY IN EXPERIMENT

Table F-1 Flexibility Cost in Each Experiment Game

Participant No.	Flexible1		Flexible2		Flexible3		Flexible4		Flexible5		Flexible6		Avg Cost of Flex
	Total Cost of Flex	No. times Purchased Flex	Total Cost of Flex	No. times Purchased Flex	Total Cost of Flex	No. times Purchased Flex	Total Cost of Flex	No. times Purchased Flex	Total Cost of Flex	No. times Purchased Flex	Total Cost of Flex	No. times Purchased Flex	
1	12	4	6	4	2	2							**2.00**
2	19	4	28	6	5	4	16	4	16	4			**3.82**
3	0	0	4	3	72	8	28	4	7	3	0	0	**6.17**
4	3	5	0	4	3	5	7	7					**0.62**
5	2	5	1	5	3	6							**0.38**
6	3	4	44	8	7	4							**3.38**
7	0	6	0	5	1	6	2	6					**0.13**
8	1	6	0	5	0	4							**0.07**
9	3	4	8	6	17	7							**1.65**
10	14	7	5	6	8	6							**1.42**
11	10	5	7	5	6	6	1	6					**1.09**
12	9	5	17	6	24	6	44	8	21	6	13	5	**3.56**
13	35	8	9	6	11	5	11	6	13	6	11	5	**2.50**
14	15	6	20	5	35	7	20	5	54	9			**4.50**
15			6	7	15	7	6	5	15	7	3	5	**1.45**
16	0	5	1	5	3	5							**0.27**
17	7	6	9	5	10	6							**1.53**
18	1	4	1	4	4	5							**0.46**
19	8	5	1	5	1	6							**0.63**
20	9	6	3	5	10	8							**1.16**
21	1	4	10	6	20	7	15	6					**2.00**
Average($)													**1.85**

Note: Unit: $1,000

'Total Cost of Flex' represents the total cost paid to delay decision in one game.

'No. Times Purchased Flex' represents number of times flexibility was purchased in one game

'Avg Cost of Flex' means the average cost for each delay decision.

A cost of flexibility versus performance graph from 82 Flexible Games does not indicate an optimum range of cost of flexibility to get best performance, as shown in Figure F-1.

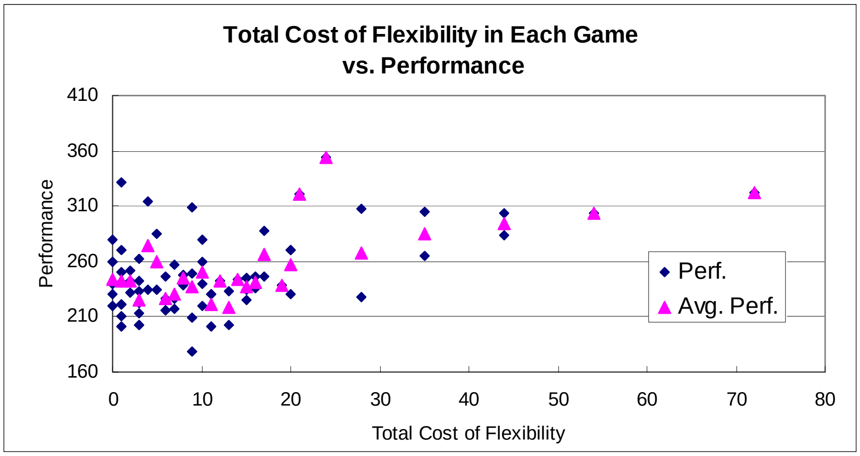

Figure F-1 Total Cost of Flexibility in Each Game vs. Performance

Number of delays versus performance graph also does not indicate an optimum number of delays to get best performance, as shown in Figure F-2.

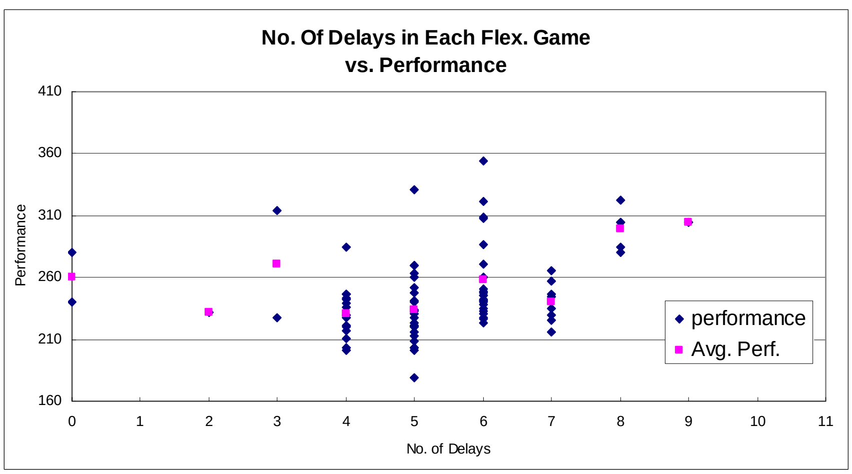

Figure F-2 No. of Delays in Each Flex. Game vs. Performance

APPENDIX G

SUBJECT'S PERCEPTION OF THE RELATIONSHIP BETWEEN THE VALUE OF FLEXIBILITY AND UNCERTAINTY

Interview Questions:

1) If you played the Flexible Game again exactly as we just did EXCEPT systems that would share a corner with a previously installed system can be successfully installed as well as systems that would share a edge, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?

Table G-1 Interview Answers B

		Answers	
		I	
Participant No.	**Level of Risk-Aversion**	Change in using of flex if system interface constraints changes	Change in savings due to flex if constraints changes
1	1	-1	-1
2	3	-1	-1
3	3	-1	-1
4	1	-1	-1
5	2	-1	-1
6	3	-1	-1
7	3	-1	2
8	1	-1	1
9	2	-1	-1
10	1	-1	2
11	3	-1	2
12	3	-1	-1
13	3	-1	-1
14	3	-1	2
15	1	-1	2
16	1	-1	-1
17	1	-1	-1
18	1	-1	-1
19	1	-1	-1
20	1	1	1
21	1	-1	-1

Notes: Answers: 1:More Delay(Net Saving); 0:Same Strategy(Net Saving); -1:Less Delay(Net Saving); 2: no idea

APPENDIX H

SUBJECT'S PERCEPTION OF THE RELATIONSHIP BETWEEN THE VALUE OF FLEXIBILITY AND FLEXIBILITY EXPIRATION TIME

Interview Questions:

1) If you played the Flexible Game again exactly as we just did EXCEPT that it takes four weeks instead of two weeks to transport systems from Fabrication to Dock, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?

Table H-1 Interview Answers C

		Answer	
		II	
Participant No.	**Level of Risk-Aversion**	Change in using of flex if duration from system leaving the fabrication to the dock increases	Change in savings due to flex if duration increases
1	1	-1	-1
2	3	1	1
3	3	1	1
4	1	-1	-1
5	2	1	1
6	3	1	1
7	3	1	2
8	1	1	-1
9	2	-1	-1
10	1	1	2
11	3	0	0
12	3	1	-1
13	3	1	1
14	3	-1	2
15	1	1	2
16	1	1	1
17	1	1	1
18	1	2	-1
19	1	0	0
20	1	0	0
21	1	1	1

Notes: Answers: 1:More Delay(Net Saving); 0:Same Strategy(Net Saving); -1:Less Delay(Net Saving); 2: no idea

APPENDIX I

SUBJECT'S PERCEPTION OF THE RELATIONSHIP BETWEEN THE VALUE OF FLEXIBILITY AND ASSET VALUE.

Interview Questions:

a). If you played the Flexible Game again exactly as we just did EXCEPT that each operation cost $5,000 instead of $10,000, and the Flexibility Cost is half of what it was previously, would you delay your decision more often? Would net savings be [same, higher, lower]? How? Why?

b). Suppose you are the project manager of a small construction company, will you use different flexibility policies on a between small project and a huge project. The failure of the huge project will lead to the bankrupt of your company

Table I-1 Interview Answers D

		Answers			
		III a		III b	
Participant No.	Level of Risk-Aversion	Change in using of flex if units costs and exercise cost are both lower	Change in savings due to flex if unit costs and exercise cost are both lower	Change in using of flex if units costs are lower	Change in savings due to flex if unit costs are lower
1	1	0	0	3	3
2	3	0	0	3	3
3	3	0	0	3	3
4	1	0	0	3	3
5	2	0	0	-1	-1
6	3	0	0	-1	-1
7	3	1	3	3	3
8	1	-1	-1	3	3
9	2	1	1	3	3
10	1	0	0	-1	-1
11	3	1	1	-1	-1
12	3	0	0	-1	-1
13	3	0	0	-1	-1
14	3	1	3	3	3
15	1	0	0	1	1
16	1	0	0	-1	-1
17	1	0	0	-1	-1
18	1	0	0	3	3
19	1	0	0	3	3
20	1	0	0	-1	-1
21	1	0	0	-1	-1

Notes: Answers: 1:More Delay(Net Saving); 0:Same Strategy(Net Saving); -1:Less Delay(Net Saving); 2: no idea ; 3: not evaluated

APPENDIX J

SIMULATION MODEL

The simulation model consists of three main subsystems: Installation Subsystem, Strategy Subsystem and Cost Subsystem, which is explained in following. Refer to the Model Structure section for part of model. Following is other part of the model. J.1 is the Rigid Game Policy switch and other extreme policies in the model. J.2 is the uncertainty model part. For details of model and equations refer to the Model included in the attached CD.

J.1 Rigid Game Policy

J.1.i Rigid Game Policy Switch

Policies in the Rigid Game include: All-Guts Strategy; All-Test Strategy; Random Strategy; Rigid Game Best Choice Strategy (including Risk-averse – X Strategy) and Subjects' Rigid Game Best Policy as discussed in Model Structure Section. Policy in Rigid Game decides "Test System Leaving Fabrication?" which decides the Installation Subsystem.

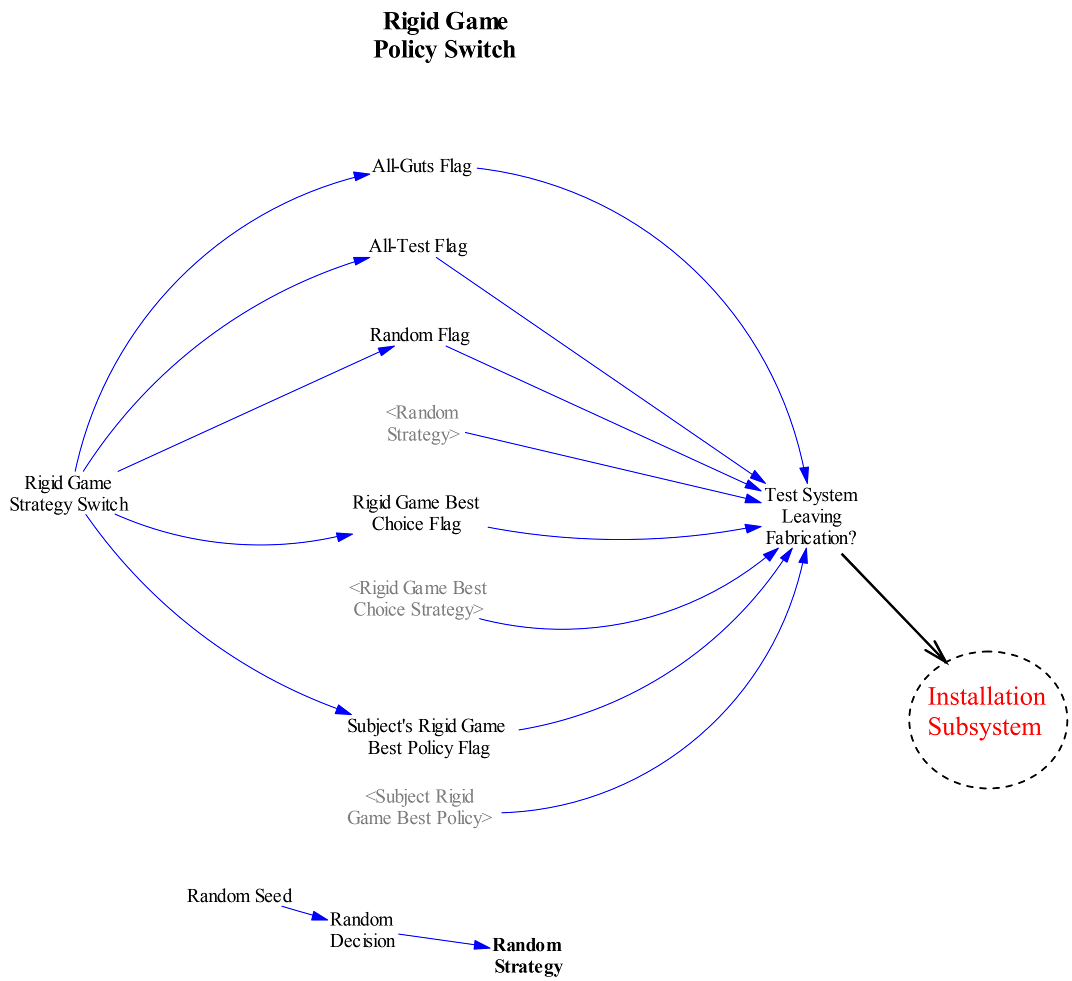

Figure J-1 Rigid Game Policy Switch

J.1.ii Rigid Game Best Choice Strategy

Rigid Game Best Choice Strategy includes ‘Typical Rigid Game Strategy Flag’ (User can input his decision for each system to test the model reproduction.); Risk-averse – X Strategy as discussed in the Model Structure section, Project Site Condition Strategy, Sys. on Board Strategy and Project Site Strategy (all these strategies are based on conditions of the game board and make decision, which were explained in details in later of this Appendix.

Figure J-2 Rigid Game Best Choice Strategy

Project Site Condition Strategy means test system until sum of Sys. Installed and Installable Sys. equals or is larger than the threshold. This strategy only consider the systems on site and sum of interface constraints met based on the project site, which does not consider other systems may stored on Tested Systems, System with Problem, Redesigned System, Rebuilt Systems stocks.

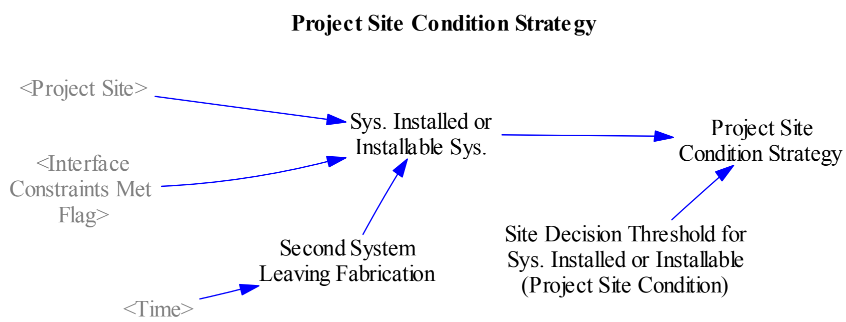

Figure J-3 Project Site Condition Strategy

Sys. on Board Strategy means test systems until number of Sys. Leaving Dock equals or is larger than the site decision Threshold. This strategy only counts the nubmer of the systems that have left dock, which do not consider how many systems have met the interface constraint when making next decision for system leaving fabrication. Larger Z is, smaller Risk he/she takes.

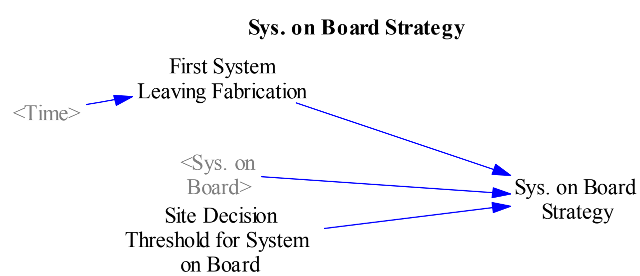

Figure J-4 System on Board Strategy

Project Site Strategy means test system until number of Sys. Installed equals or is larger than the threshold. This strategy only counts the number of the systems that have been installed, which do not consider how many systems have met the interface constraint and systems maybe stored on board besides on Project site when making next decision. Larger A is, smaller Risk he/she takes.

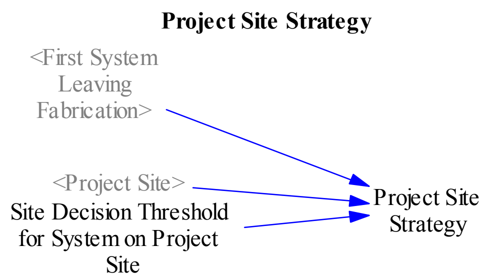

Figure J-5 Project Site Strategy

J.4.iii Subject Rigid Game Best Policy

As mentions in the Model Use section, Subjects' Rigid Game Best Policy was modeled as:

If p(successful) > Site Decision Attractiveness Threshold

Then Decision for the next system leaving fabrication is *'to Site'*

Else Decision for the next system leaving fabrication is *'to Test'*

Different Site Decision Attractiveness Threshold values were used for different levels of risk-aversion.

Table J-1 Site Decision Attractiveness Threshold

Risk-aversion Level	**Site Decision Attractiveness Threshold**
Risk-averse	High [0.7, 0.8, 0.9]
Risk-neutral	Medium [0.4, 0.5, 0.6]
Risk-seeking	Low [0.1, 0.2, 0.3]

If Flexible Game is played than Flexible Game Site Decision Threshold = 0.9 is active. Future research can use different threshold for different levels of Risk-aversion.

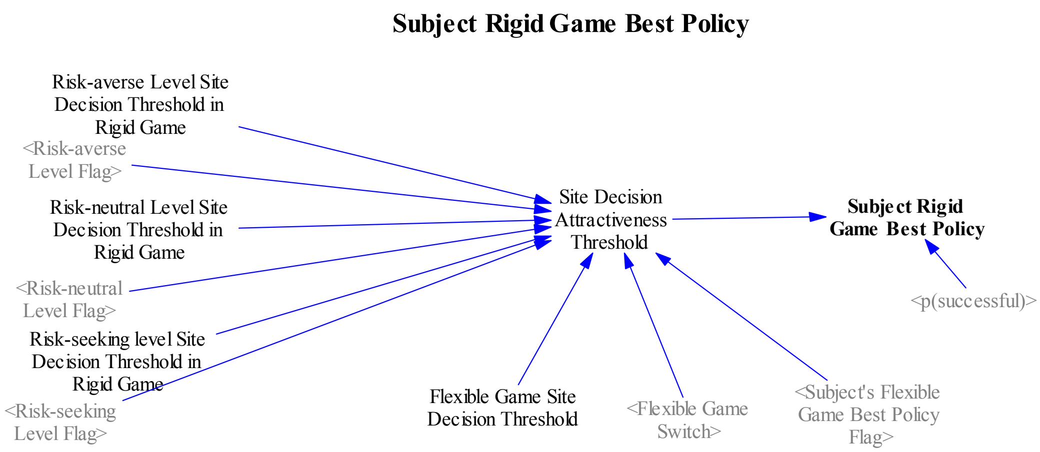

Figure J-6 Subject Rigid Game Best Policy

J.2. Uncertainty

For Details refer to the Hypothesis Test section. First system leaving fabrication's p(f) = 0, since it is guaranteed can be installed directly. Second system leaving fabrication's p(f) is unknown, since no system is revealed. But the range is from 11/15 (if the first system's position is in the center of the project site) to 13/15 (if the first system's position is on the corner of the project site). Last two systems leaving fabrication's p(f) = 0, since they are guaranteed can be installed directly. p(f) = Sys. with constraints not met and not leaving Dock"/"Sys. not arrived Dock".

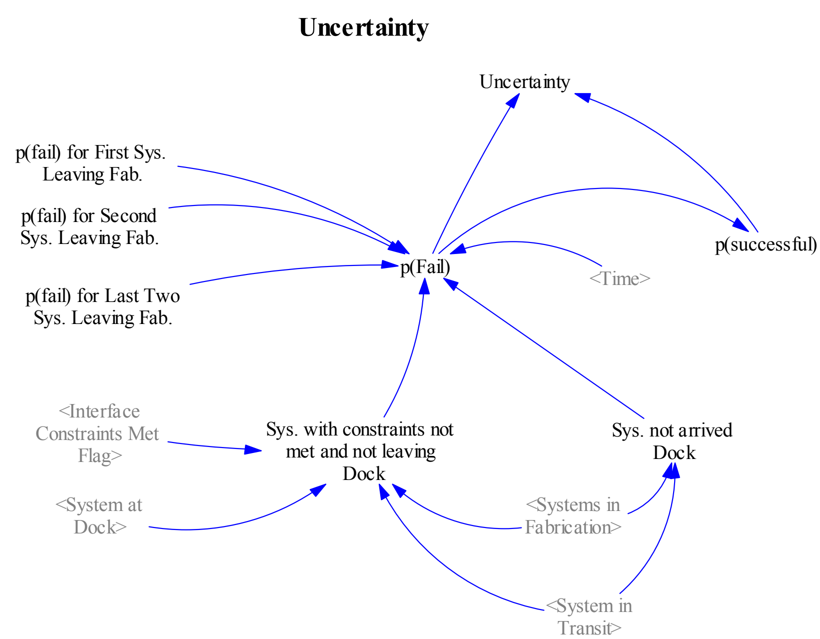

Figure J-17 Uncertainty

APPENDIX K

MODEL PERFORMANCE ANALYSIS

OF EXTREME RIGID GAME POLICIES

Table K-1 Performance of Extreme Rigid Game

Strategy	Min.	Max.	Range by Analysis
All-Guts	160	550	390
All-Tests	320	320	0
Random	160	550	390
Risk-Averse	230	290	60

Unit: $1,000

All-Guts Strategy:

Minimum Cost: $160,000 = 16 * $10,000

All systems were successfully installed, when the sequence of systems arriving at the dock were each adjacent to a previously installed system on the project site. Each of the 16 systems only cost $10,000.

Example:

System Transport Order Seed: 137

System Sequence: 15, 11, 10, 6, 9, 14, 7, 2, 8, 13, 5, 16, 4, 1, 3, 12

All systems can be successfully installed without testing.

Maximum Cost: $54,000 = 3 * $10,000 + 13 * $40,000

If the sequence of systems arriving at the dock was not adjacent to a previous installed system, then a maximum of 13 systems would fail. Then, three systems successfully installed at a cost of $10,000 each, 13 systems failed and each costs $40,000.

Example:

System Transport Order Seed: 173

System Sequence: 1, 8, 9, 16, 13, 12, 7, 14, 3, 10, 4, 15, 6, 11, 2, 5

Only 1, 2, 5 can be successfully installed without testing, the others are failed to install.

All-Tests Strategy

All systems are tested. Each system cost $20,000 no matter what the sequence was. Cost: $10,000*16*2=$ 320,000.

Random Strategy

Minimum cost and Maximum cost Random Strategy is same as All-Guts Strategy.

Minimum Cost: $160,000 = 16 * $10,000

All decisions are ‘to Site’ and all systems were successfully installed, when the sequence of systems arriving at the dock were each adjacent to a previous installed system on the project site. Each of the 16 systems only cost $10,000.

Maximum Cost: $54,000 = 3 * $10,000 + 13 * $40,000

All decisions are ‘to Site’ but the sequence of system is not good. If the sequence of systems arriving at the dock was not adjacent to a previous installed system, then a maximum 13 systems would fail. Then, three systems successfully installed at a cost of $10,000 each, 13 systems failed and each costs $40,000.

Risk-averse Strategy

Minimum Cost: $230,000 = 9 * $10,000 + 7 * $20,000

If the sequence of the first couple of systems installed are adjacent to each other, than only 7 systems need to be tested before the other systems are guaranteed to be installed successfully without testing.

Example:

System Transport Order Seed = 84

> System Sequence: 7, 10, 2, 9, 3, 12, 11, 13, 4, 5, 15, 8, 1, 6, 16
>
> Only systems 10, 2, 9, 3, 12, 11, 13 need to be tested, other systems are guaranteed to be installed without testing.

Maximum Cost: $290,000 = 3 * $10,000 + 13 * $20,000

If the sequence of the first couple of systems is not of systems adjacent to each other, then up to 13 systems need to be tested before the other systems are guaranteed to be installed.

Example:

System Transport Order Seed = 173

System Sequence: 1, 8, 9, 16, 13, 12, 7, 14, 3, 10, 4, 15, 6, 11, 2, 5

Only systems 1, 2, 5 are guaranteed not to fail installation, others are shipped to the yard to be tested before installation.

APPENDIX L

SIMULATED RISK-AVERSE – X STRATEGY PERFORMANCE IN RIGID GAME

Table L-1 Simulated Risk-averse – X Strategy Performance in Rigid Game

X	Mean	Median	Std. Dev.	Skewness	25% Confidence Band	75% Confidence Band	Simulated Min.	Simulated Max.	Simlated Range
0	268	270	12.0	-0.35	260	280	230	290	60
1	259	260	14.1	0.12	250	270	220	310	90
2	255	255	17.9	0.72	240	260	220	330	110
3	253	250	22.1	0.97	240	260	210	350	140
4	254	250	27.0	1.24	240	270	200	370	170
5	257	250	32.3	1.10	230	280	200	390	190
6	260	255	37.3	1.10	230	280	190	410	220
7	267	260	42.2	0.98	240	290	190	430	240
8	273	270	46.8	0.88	240	300	180	450	270
9	282	280	51.7	0.77	250	310	180	470	290
10	291	280	55.4	0.66	250	330	180	490	310
11	303	300	58.5	0.63	270	330	180	510	330
12	313	320	61.8	0.57	275	350	170	530	360
13	326	310	64.8	0.56	280	370	160	550	390

Unit: $1,000

VITA

Yanzhen Wu was born on August 2, 1981 in Pujiang, China. She studied Civil Engineering for three years and studied International Economics and Trade for two years. She graduated from Zhejiang University of Technology in July, 2003 with a Bachelor degree in Economics. She was honored as an outstanding student scholar for five consecutive years and she graduated as an Outstanding Student of Zhejiang Province. She started her Master studies in August, 2003 at Texas A&M University (TAMU), where she worked with Dr. Ford on Real Option research group. During studies at TAMU, she received a Civil Engineering Department Fellowship twice.

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