IMPACTS OF PROJECT MANAGEMENT ON REAL OPTION VALUES

A Thesis

by

SHILPA ANANDRAO BHARGAV

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

December 2004

Major Subject: Civil Engineering

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Approved as to style and content by:

David Ford (Chair of Committee)	Stuart Anderson (Member)
Joe Horlen (Member)	Paul Roschke (Head of Department)

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ABSTRACT

Impacts of Project Management on Real Option Values. (December 2004)

Shilpa Anandrao Bhargav, B.E., University of Pune

Chair of Advisory Committee: Dr. David N. Ford

The cost of construction projects depends on their size, complexity, and duration. Construction management applies effective management techniques to the planning, design, and construction of a project from conception to completion for the purpose of controlling time, cost and quality. A real options approach in construction projects, improves strategic thinking by helping planners recognize, design and use flexible alternatives to manage dynamic uncertainty. In order to manage uncertainty using this approach, it is necessary to value the real options. Real option models assume independence of option holder and the impacts of underlying uncertainties on performance and value. The current work proposes and initially tests whether project management reduces the value of real options. The example of resource allocation is used to test this hypothesis. Based on the results, it is concluded that project management reduces the value of real options by reducing variance of the exercise signal and the difference between exercise conditions and the mean exercise signal.

DEDICATION

Dedicated to Aai, Papa, Dada and Monish

ACKNOWLEDGMENTS

I would like to thank my committee chairman, Dr. David Ford, for giving me an opportunity to pursue this research. I am grateful to him not only for his academic guidance but also for his continuous support, encouragement and patience during the course of my research.

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I. INTRODUCTION

Project Management

The application of effective management techniques to the planning, design, and construction of a project from conception to completion for the purpose of controlling time, cost and quality and eventually improving project performance can be termed as project management. The cost of construction projects depends on their size, complexity, and duration. Factors that influence construction project success include clarity of project objectives, detailed specification of plan and a good schedule, client consultation and involvement, and effective monitoring and controlling of the project. Construction projects can be highly complex. Comprehensive management of every stage of the project, beginning with the original concept and project definition, yields the greatest possible value in terms of project performance.

The construction industry traditionally evaluates success based on individual project performance. There has been a consistent evolutionary change in project management methods, from the development of Critical Path Method to the development of modern, computer-based scheduling and estimating systems. This research focuses on a real options approach to project management and specifically on construction management.

The Role of Flexibility in Project Management

Flexibility in project management is the ability of a system to respond to unforeseen changes (Evans, 1982). According to Amram and Kulatilaka (1999), managers are often faced with decisions requiring the valuation of flexibility. Flexibility includes flexible manufacturing systems, options to change the product mix in oil refineries, and the opportunity to temporarily shut down and restart equipment. Flexibility also includes options to switch production across locations, depending on local labor conditions, demand, and currency fluctuations.

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

An example of managerial flexibility is the ability of project managers to delay committing to certain investment decisions, or to reverse or change earlier decisions. Some examples of flexibility found in the literature include:

- Flexibility to defer allows the decision maker to delay taking an action until uncertainties are favorable (e.g., one may gain some lease such as a right-of-way contract that grants him/her the right to defer; (Dixit and Pindyck 1993)
- Flexibility to expand or contract allows the decision maker to increase or decrease the system capacity scale when a trend of higher or lower system demand is formed (Kumar 1995). For example, in a construction project the project manager has the flexibility to increase the number of shifts of work if required due to schedule constraints. Increasing the number of shifts will add value to the project in terms of total resources and thus help maintain the project schedule. A public parking garage with the flexibility to expand with increasing demand is another example of flexibility in construction.
- Flexibility to switch allows a system operator to switch to different technologies or resources (Kulatilaka 1993). A construction contract can have the flexibility to switch between using in-situ concreting or pre-fabricated concrete structures. Pre-fabricated concrete structures can save time and site space, adding value to the project.

Managing uncertainty in any project is one of the most challenging problems faced by any project manager. Real option thinking allows for flexibility that is often missing in more traditional approaches and helps manage uncertainty. Miller and Lessard indicate that the success of large engineering projects depends on the ability of the project managers to manage uncertainty. According to Miller and Lessard (2000), flexibility lets projects to undergo rescheduling, restructuring or even bankruptcy, thus enabling them to survive many unforeseen events. The dynamic uncertainties involved in construction projects call for the use of flexible strategies to face uncertainty as it evolves. Weitzel and Jonsson (1989) state that "firms that fail to make flexible strategic choices may enter into organizational decline" owing to the failure to adapt to dynamic environments. Sharfman and Dean (1997) suggest that organizations will flourish if managers are able to overcome their informational and ideological barriers and practice flexibility in their strategic choices. This example in the literature emphasizes the importance of flexibility in project management. Tong Zhao and Chung-Li Tseng use a case of construction of a public parking garage where a model that does not consider the value of flexibility is compared with two value-flexible models. The value of flexibility in the case study is so significant that failure to account for flexibility is not economical.

Ford et al. (2002) describe the use of options in strategic project planning as a means of improving project management. They suggest that construction project participants determine which organizations will receive the benefits and absorb the costs of dynamic uncertainties. For example, the impacts of dynamic construction cost uncertainty would be borne by the owner if a cost-plus contract were used but by the general contractor if a lump sum contract were used. The authors state that in the construction industry, design engineers, architects, owners, and contractors could apply a structured flexible approach to manage the uncertainties for which they are responsible. The authors point out that construction managers currently do not exploit real options fully to capture the value of strategic flexibility, largely because they do not use a decision-making framework to recognize or quantify estimates of the value of options.

The authors also caution that although the application of a real options approach to strategic construction project management can potentially improve construction management, additional research is required into several aspects of its implementation. This research is a preliminary step towards modeling and documenting the impact of project management on real options.

II. REAL OPTIONS IN PROJECT MANAGEMENT

Introduction to Real Options

Stewart Myers (1984) of the Sloan School of Management at MIT coined the term "real options" to address the gap between strategic planning and finance as follows:

"Strategic planning needs finance. Present value calculations are needed as a check on strategic analysis and vice versa. However, standard discounted cash flow techniques will tend to understate the option value attached to growing profitable lines of business. Corporate finance theory requires extension to deal with real options."

According to Amaram and Kutilalka, an option is the right, but not the obligation, to take an action in the future and a real option is a right without an obligation to take specific future actions depending on how uncertain conditions evolve on a real asset. Options are valuable because they provide flexibility. Non-paper assets are called real assets and options in real assets are called real options. According to Ford et al., (2002) a real options approach in construction projects, improves strategic thinking by helping planners recognize, design and use flexible alternatives to manage dynamic uncertainty.

The traditional analysis without options assumes a "now-or-never" investment opportunity. It ignores another alternative which may be profitable, namely waiting to invest at a later date. This research focuses on applying the real options approach to the management of construction projects.

According to Trigeorgis (1996), just as corporate liabilities can be viewed as collections of call or put options on the value of the firm, similarly, real investment opportunities can be seen as collections of similar real call and put options on the value of the project. And just as option-based valuation can be useful in quantifying the value of flexibility in financial instruments, so can it be useful in quantifying the value of operating flexibility and strategic adaptability implicit in real opportunities. Flexibility can be viewed as the collection of options associated with an opportunity, be the asset financial or real.

According to Amram and Kultilaka (1999) an option is the opportunity to make a decision after you see how events unfold. Traditionally the real options approach uses financial market inputs and concepts to value complex payoffs across all types of real assets. Real-options-based decision making recognizes the value of flexibility. Options thinking can be used to design and manage strategic investments proactively. Alessandri (et al., 2004) suggests that real options encourage:

- an emphasis on outcomes, not solutions;
- an emphasis on multiple futures, even after a project has started;
- an emphasis on continuous testing of the strategy as it evolves; and
- the proper valuation of the flexibility built into a project managed using real options thinking.

Ford, Lander, and Voyer (2002) demonstrate the potential benefits of applying real options approach to the strategic planning of construction projects. Managing uncertainty can maximize project value. Until now, uncertainty has had a negative connotation. According to the authors, project managers focus on uncertainty in terms of potential losses and try to mitigate any undesirable impacts of such uncertainty. However, in such cases, significant project value may remain hidden and hence unexploited.

Alessandri (et al., 2004) use the example of The National Ignition Facility to illustrate how practicing planners and managers can identify risks and uncertainties in development projects, then use and identify flexibility in project analysis, thus increasing their project worth. Based on approximately 60 large projects studied by IMEC, Miller and Lessard, (2000), found that 40% of these projects performed very badly due to instabilities created by exogenous and endogenous shocks. Effective management of the project can help handle the instability due to uncertainty. Thus, project management purposefully and significantly manipulates the impact of uncertainties on performance and value.

Components of Real Options

The basic components that are useful to value a call option on a financial asset are:

- Assets: For financial options assets are traded securities in the financial market whose fluctuations largely determine the value of the option.
- Exercise price: The specified price at which the contract may be exercised, whereby a buyer can buy or a buyer can sell the asset.
- Option price: It is the amount per share that an option buyer pays to the seller.
- Volatility: It is the relative rate at which the price of a security moves up and down. If the price of a stock moves up and down rapidly over short time periods, it has high volatility. If the price almost never changes, it has low volatility.
- Expiration date: The date on which an option, right or warrant expires, and becomes worthless if not exercised. It is also, the date on which an agreement is no longer in effect.
- Risk free rate of return: It is a theoretical interest rate that would be returned on an investment which was completely free of risk.
- Dividends: A taxable payment given to the shareholders of the company from its current or retained earnings. Cash flows from a project are similar to dividends on a stock.

Ng et al. (2002) have used real options analysis to compare the cost of a long-term contract with a price cap to that of spot purchases in construction material procurement. In construction, material procurements are usually short-term, project-based, and have a price volatility of up to 30%. According to the authors, it has been observed that contractors purchase a stable amount of commodity materials such as concrete, structural steel, and lumber throughout the year. For contractors, the price cap reduces the price volatility of materials without their being obliged to a quantity; for suppliers, the contracts give them steady demand and a bigger market share. The authors evaluate this contract as a real option and solve for the contractor's optimal ordering policy. The contract has a real option because it provides the flexibility to buy at the cap price when the price is high and the option to buy at the spot price when the price is low. The contract is evaluated using correlation pricing and Monte Carlo simulation. A comparison of the real option and financial option in this example can be made by using Figure 1:

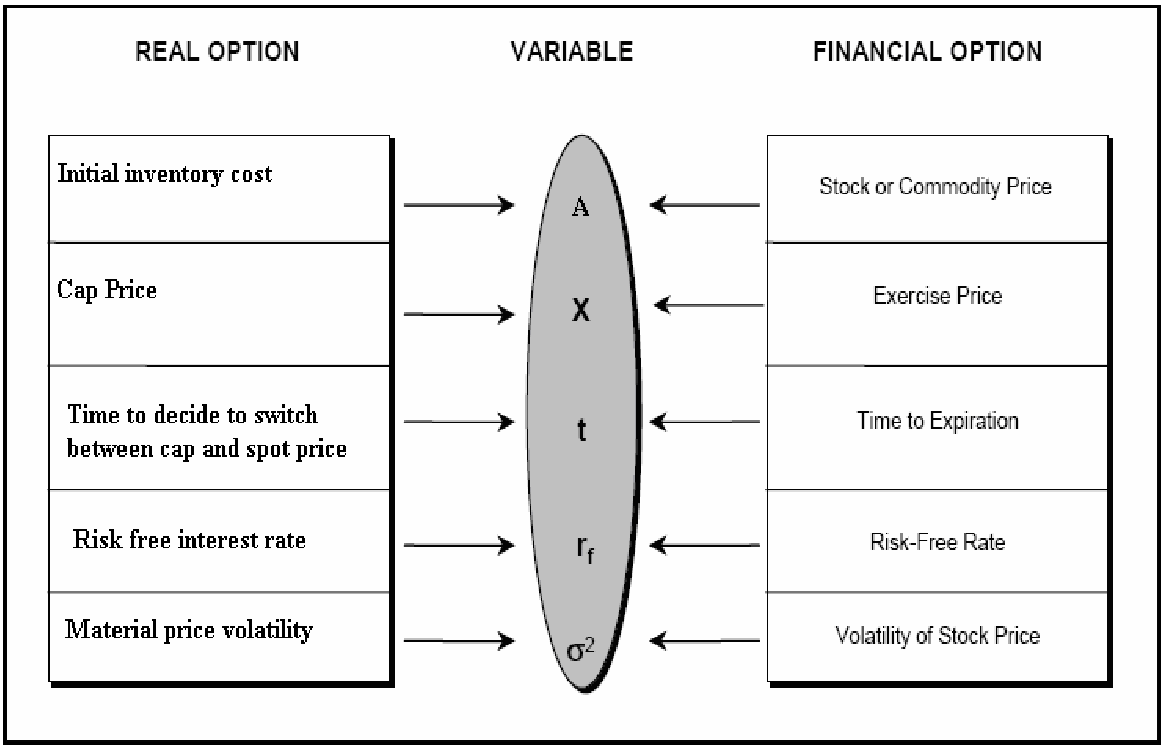

Fig.1. Equivalence between financial and real options (after Booz, Allen and Hamilton, 1999)

A call option gives the buyer of the option the right to buy the underlying asset at a fixed price, called the strike or the exercise price, at any time prior to the expiration date of the option: the buyer pays a price for this right. A put option gives the buyer of the option the right to sell the underlying asset at a fixed price, again called the strike or exercise price, at any time prior to the expiration date of the option. The buyer pays a price for this right. An American option can be exercised at any time between the purchase date and the expiration date. This is the opposite of a European-style option, which can only be exercised on the date of expiration. An American option provides an investor with a greater degree of flexibility than a European style option. European option can only be exercised for a short, specified period of time just prior to its expiration, usually a single day. Asian option is an option whose payoff depends on the average value of an asset over a specified period.

Table 1 reflects the changes in the prices of call and put options:

Table 1. Real Option Value Characteristics (after Brealy and Myers, 2000 and Damodaran, 2002)

Increase in variable	Call Option Value	Put Option Value
Asset Value	Increases	Decreases
Exercise Price	Decreases	Increases
Interest rate	Increases	Increases
Time to expiration	Increases	Increases
Volatility	Increases	Decreases

Real Options as a Strategy

Real options can be used for making project capital investment decisions as well as for strategic decisions within the scope of a single project. The use of real options for capital investment decisions addresses the question "In which project should the capital be invested?" In contrast, the use of real options for strategic management addresses the question "How flexibility should be used to manage this project?" It is important to distinguish between the two since this work concentrates on using real options in the latter case.

Ford et al. (2002) give a simplified application of a real options approach to strategy design. A hypothetical large construction firm is preparing a proposal for the government of a developing country to construct and operate a toll road for 20 years. Procurement of materials will remain with the firm. There are two issues the planners face. They are the timing of design and procurement and the uncertainty of construction prices. Two alternatives have been identified. Alternative A is the Basic Design strategy and alternative B is the Engineered Design strategy.

In alternative A, post-award project planning is expected to take a year. Design and contract document preparation could then be completed in an additional two years, at the earliest. The procurement of construction services could then begin. However here, the design cannot be value engineered or cannot include any productivity modifications due to schedule constraints.

In alternative B the design will be value and productivity-engineered. Since both value and productivity-engineering require the majority of the design to be completed before they can begin, the six months required for value and productivity engineering would delay the completion of contract documents and the start of procurement by six months. It provides no flexibility to capture more project value as cost uncertainty is resolved. Hence a flexible strategy that would postpone the decision on choice of strategy, until the cost uncertainty is partially resolved is needed. The authors conclude that the flexibility provided by the flexible design strategy adds both monetary value and strategic value to the toll road project as shown in the Table 2.

Table. 2. Estimated project values using three design strategies for toll road project example (after Ford et al., 2002)

Design strategy	Estimated project value	Improvement over basic design strategy	Improvement over engineered design strategy
Basic	0.71	0.00	N.A.
Engineered	1.71	1.00	0.00
Flexible	2.18	1.47	0.47

Although the valuations from different pricing models differ, it is still recommended that the planners use the flexible design strategy. By identifying and designing the different paths in the project, the firm changes its planning and managing view from a narrow and constrained way to a broader spectrum of scenarios that they can choose from.

Real Option Valuation Techniques

According to Ford et al. (2002), valuing real options in projects has been demonstrated to potentially increase project value. For improving strategic decision making and hence project performance, there is a need to value real options.

First, the breakthrough work by Black, Scholes and Merton (Black and Scholes, 1973; Merton, 1973) determined a close form solution to price European call and put options. The price of a real option can also be determined by identifying the partial differential equation that describes the behavior of the underlying asset (e.g., a Geometric Brownian Motion or a Markov Process) and solving this equation through the use of Ito Calculus (Dixit and Pindyck, 1994).

The Black-Scholes solution is easy to use; five inputs and one equation are all that are needed to compute the value of the option. The Black-Scholes equation for a call option, the definition of the variables, and an interpretation of the equation are shown in Figure 2.

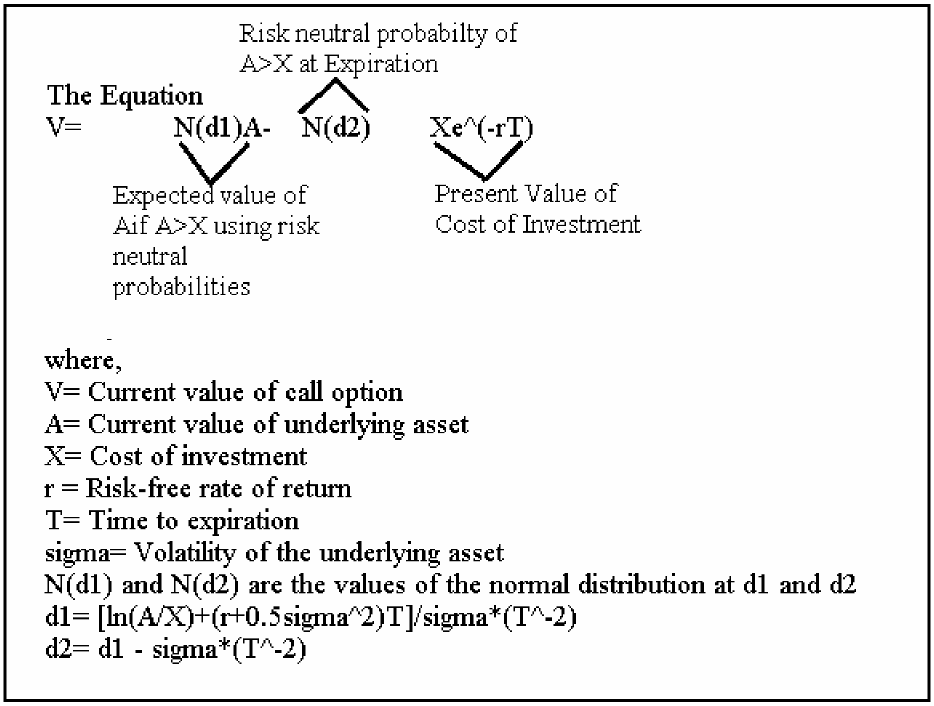

Fig. 2. Black – Scholes equation for a call option (after Amram and Kulathilaka, 1999)

The information that is and is not needed to value an option is described in Table 3.

Table 3. Information for Valuing Options (after Amram and Kulthilaka, 1999)

Information needed to value an option	Information not needed to value an option
The current value of the underlying asset, which is observed in the market.	Probability estimates are not needed because these are captured by the current value of the underlying asset and the volatility estimate.

Table 3 (continued)

Information needed to value an option	Information not needed to value an option
The time to the decision date, which is defined by the features of the investment	An adjustment to the discount rate for risk is not needed because the valuation solution is independent of anyone's taste for risk.
The investment cost or exercise price (also called the strike price), which is defined by the features of the investment	The expected rate of return for the underlying asset is not needed because the value of the underlying asset and the ability to form tracking portfolios already capture its risk/return tradeoff.
The risk-free rate of interest, which is observed in the market.	The expected rate of return of the option is not needed because the option is valued directly by dynamic tracking.
The volatility of the underlying asset, which is often the only estimated input.	-
Cash payouts or non-capital gains returns to holding the underlying asset, which are often directly observed in the market, or sometimes estimated from related markets.	-

Decision Analysis effectively takes into account the value of flexibility by structuring the problem in such a way that all uncertainties and their contingent decisions on those uncertainties are explicitly represented by a decision tree. A decision tree is a sequence of decision and chance nodes, ending on a terminal node. A decision node indicates a point where the decision maker faces a decision. The branches emanating from a decision node represent the options available to the decision maker; all possible choices should be represented and they have to be mutually independent. According to de Neufville, (2001) decision tree recognizes that only uncertainty resolution reveals the most appropriate decision at each point in time, and therefore it does not pre-commit to a decision in the first time period, but identifies an array of decisions, each of which is optimal under different evolutions of the uncertainties in the project. Decision Analysis differs from NPV in that it does not base its decisions on information available today, but assumes that new information will be acquired as the project evolves and that this information may change the optimal choice for the project.

Perdue et al. (1999) present methodology for combining options-pricing techniques and decision analysis tools to evaluate research and development projects. They use an options-pricing model to capture a project's value at the commercial stage, including the value of the option to delay or abandon the project due to unfavorable market conditions. They use a decision tree to represent technical success uncertainties and key research and development decision points.

The Binomial Method, developed by Cox, Ross and Rubinstein (1979), uses binomial trees (develop a binomial lattice that mimics the stochastic process of the asset's value) to approximate the behavior of the underlying asset. The key insight of the risk-neutral approach is that, because the option values are independent of everyone's risk preferences, the same valuations will be obtained even when we assume that everyone is indifferent to risk, or risk-neutral. This assumption simplifies calculations enormously because we do not need to estimate the premium for risk in the discount rate, because no investor requires compensation for taking on risk. A particularly simple, yet robust, implementation of the risk-neutral approach is the binomial option valuation model, in which the underlying asset moves up or down by a small amount in each short period.

There are three advantages to the binomial option valuation model:

- It spans a large range of real option applications, including those with some complexity.
- The approach is comfortable for many users because, although it is consistent with the option valuation breakthrough, it retains the appearance of discounted cash flow analysis.

- Uncertainty and the consequences of contingent decisions are laid out in a very natural way; the binomial model generates good visual images.

Simulation techniques replicate the underlying asset stochastic process by using random numbers to sample many different paths that the underlying asset's value may follow (usually this is done through a Monte Carlo simulation) in a risk-neutral environment. According to Amram and Kulthilaka (1999), simulation models have thousands of possible paths of evolution of the underlying asset from the present to the final decision date in the option. The current value of the option is found by averaging the payoffs and then discounting the average back to the present. The simulation method can handle many aspects of real-world applications, including complicated decision rules and complex relationships between the option value and the underlying asset. Also, adding new sources of uncertainty to a simulation analysis is computationally easier than in the other numerical methods. The current work uses simulation to value real options.

There are several methodologies to value an option. The discounted cash flow procedures fail to recognize that effective management of the risks enhances the value of the system when applied to systems operating in an uncertain environment. These methods are still adequate for calculating present values of unchanging projects, for example the return on a fixed annuity, or of investments that once made are not managed, such as the insulation of a building. The "real options" approach overcomes the flaws of discounted cash flow analysis. Most importantly, it explicitly recognizes the value of flexibility and the additional value associated with options in the context of uncertainty, especially when system operators can manage these uncertainties.

III. CHALLENGES IN VALUING REAL OPTIONS IN PROJECT MANAGEMENT

Traditional Model Assumptions

Traditional real option valuation models assume independence of option holder and the impacts of underlying uncertainties on performance and value. There is a need to capture realistic behaviors, and thereby capture the practical value of flexibility. The system dynamics approach offers a project model which appears to reflect the real experiences of projects. A computer based system dynamics simulation model leads to a greater understanding of the system and encourages experiments to explore new management options.

Some problems encountered when valuing real options have been documented by Fernández (2001):

- "Difficulty in communicating the valuation due to its higher technical complexity than the net present value (NPV).
- Difficulty in defining the necessary parameters for valuing real options.
- Difficulty in defining and quantifying the volatility of the sources of uncertainty.
- Valuation of real options is much less accurate than the valuation of financial options since all market and financial data cannot be included in real option analysis."

Damodaran (2002), on application of option pricing models to equity valuation, cautions for the following:

- "The underlying asset is not traded. Option pricing theory is built on the premise that a replicating portfolio can be created using the underlying asset and risk-less lending and borrowing.
- The price of the asset follows a continuous process. The Black-Scholes option pricing model is derived under the assumption that the underlying asset's price process is continuous, that is., there are no price jumps.

- The variance is known and does not change over the life of the option. The assumption that option pricing models make, that the variance is known and does not change over the option lifetime, is not unreasonable when applied to listed short-term options on traded stocks. When option pricing theory is applied to long-term real options, there are problems with this assumption, since the variance is unlikely to remain constant over extended periods of time and may in fact be difficult to estimate in the first place.
- Exercise is instantaneous. The option pricing models are based upon the premise that the exercise of an option is instantaneous. This assumption may be difficult to justify with real options, where exercise may require the building of a plant or the construction of an oil rig, actions which are unlikely to happen in an instant."

Most of the real options literature is based on the premise that the real options holder is independent of the underlying uncertainty that influences project value. The key challenge is the appropriateness of the assumptions used to model financial assets with option pricing models for modeling construction project benefits and costs over time. Improved estimates are required in calculating discount rates where they control option selection.

Conflict of Traditional Model Assumptions with Project Management in Practice

Garvin and Cheah (2004) describe how project analysts often apply evaluation methods without regard for their assumptions and limitations. The authors make a comparison between the traditional and real option valuation. A case study of a toll road project provides the basis for examining the assumptions behind both traditional and option valuation models. According to the authors, the appropriateness of each model and approach depends on the particular context of application, which in turn dictates the validity of the assumptions underlying each model. Ho and Liang (2002) adopted a discrete-time approximation to model the stochastic processes of two log-normally distributed variables, project value and construction cost, to subsequently solve for equity value using a lattice model. Their assumptions may not be correct since project value and construction cost may not follow lognormal processes. If one considers an equity investment in the construction of a power plant or exploration of an oil field, however, utilization of a continuous-time model, with the output following a specific stochastic process, can indeed be a reasonable approach. Market prices for the output of these projects are given in the spot and future/ forward markets, so historical data can be used to determine the most appropriate stochastic process to model the underlying asset. Wey (1993) found that crude oil prices are likely to follow a mean-reverting process for a long time horizon, and evaluation of a real option contingent on oil prices could be modeled with this consideration in mind. The same argument that traffic volume (and hence toll revenues) follows a geometric Brownian motion evolvement or a mean-reverting process is would not hold.

Luehrman (1997) and Myers (1984) suggest that traditional valuation methods are adequate for investment decisions regarding assets-in-place. The risk of cash flows can change as project develops or new information is received. In such cases, DCF methods understate the value of flexibility, and Amram and Kulatilaka (1999), Trigeorgis (1999), Dixit and Pindyck (1994), Myers (1984), have already pointed this shortcoming. The appropriateness of each model and approach depends on the particular context of application, which in turn determines the validity of the assumptions underlying each model.

One of the issues with real option analysis is that the underlying assumptions of the model may be violated, for example, the use of "risk-neutral probabilities" in the Black-Scholes formula which in practice is not really the case.

Defining the scope and boundaries of a project, before applying a real options approach is important. Adner and Levinthal argue that the greater the extent to which choice sets evolve as a consequence of firms' exploration activities, the less structured the firms' abandonment decisions become and, in turn, the less distinguishable a real option is from simply a sequential stream of investment in and of itself does not constitute a real option. While organizational adaptations can extend the applicability of real options, they impose tradeoffs that may lead to the underutilization of discoveries made in the course of exploration. The authors also argue that the cause of options thinking is best served in considering the boundaries of the domain of applicability of this logic for business strategy, and in defining its place within the broader set of tools that are available to address decision making under uncertainty. Hence it is important to test the applicability of a real options approach to a particular project.

Potential Impacts

Lander and Pinches (1998) provide an insight to the problem of practical implementation of real option models. According to them, assumptions about determining and modeling the state variables, input parameters, requirement of complete markets and no arbitrage opportunities can have a major impact on the valuations obtained. They suggest that corporate managers do not understand well enough the already existing models and lack mathematical skills to use the model comfortably. Secondly, the modeling assumptions required are generally violated and lastly, the necessary additional assumptions required for mathematical tractability limit the scope of applicability.

According to Ford et al (2002) the central premise of real options theory is that, if future conditions are uncertain and changing the strategy later incurs substantial costs, then having flexible strategies and delaying decisions can increase project value when compared to making all key strategic decisions early in the project. The project manager is the option holder. Project managers must therefore focus on managing uncertainty in order to add to project value.

Ford et al (2002) summarize the effects of using real options on construction project planning and management practice, as follows

- More planning and management of flexibility and thereby improved control through increased numbers of project scenarios which firms design and select from, to capture project value.
- Increased description, measurement, and management of project uncertainties.

- More purposeful and planned project strategies, managerial decisions, and actions as real options strategies are implemented.
- Increased firm competitiveness from the ability to manage uncertainty and capture latent project value.
- Expanded perceptions of uncertainty that include opportunities as well as risks.

Thus, it is suspected that project management purposefully and significantly manipulates impacts of uncertainties on performance and value. Therefore it is important to study the effect of project management on option value.

Research Question

Consider an example of project manager working for a general contractor (GC). The firm was recently awarded a large size building construction project requiring a lot of concreting over an extended period of time. This project needs to be completed by a specific due date of completion. If the project extends beyond this date, a heavy penalty will be incurred by the general contractor. The completion date directly controls the project cost as early completion will not only reduce the mean project cost but will also avoid the penalty by meeting the deadline.

Outsourcing of construction work is a common practice in the construction industry. Outsourcing transfers some of a company's activities and decision rights to outside providers, as set forth in a contract. It minimizes the labor employed, directly by the company and investment in construction plant and equipment. The decision to outsource any trade in a construction project has a great impact on the project execution and completion and is thus of paramount importance to the firm carrying out the project. Concreting is a large part of the project and will therefore be one of the key drivers of project performance. Therefore, the GC’s project manager feels that outsourcing concreting could prove to be beneficial for the project. The project manager receives two bids for the project. Provider A is an external firm, wholly owned by the GC and has an initial lower bid price, but historically also had lower productivity. Provider B is an internal division of the GC and historically has higher productivity, but has submitted a higher bid price. If the two providers generate their historical productivities on the current project, Provider A might prove expensive later in the project if he is unable to keep up with the schedule. Provider B might have an advantage here, since its historical productivity is high. Giving the contract to Provider A will be termed "out-sourcing" and for Provider B will be "in-house", hereafter.

The GC's project manager however has a contractual Union agreement to give work to Provider A. Also, Provider A is minority owned. Hence he considers three strategies. Strategy 1 is to outsource concreting. Strategy 2 is to do the work in-house. Strategy 3 is to outsource the work at the beginning of the project and retain the option to take it in-house at a later point of time, depending on the schedule performance of the project. The basic question for the project manager therefore is, how much money should the project manager be willing to spend to retain the option to self perform and at the same time meet the schedule deadline? Within this context of applying real option analysis to construction, the research question is whether and how project management impacts the option value. In other words, what is the value of the GC's project manager's option to switch from an outsourced provider to an internal provider?

More specifically,

How does project management by the holder of real options impact the value of options to improve performance?

To study this, we will use the outsourcing setting in which the project manager (the option holder in this case) influences the project through resource allocation.

IV. HYPOTHESES

In the construction project frame, the assumption that the real options holder is independent of the underlying uncertainty implies that the construction manager does not have any control over the uncertainty regarding project completion. This is not necessarily true since, managing the uncertainty can maximize project value. Given that many real options applications in project management do not conform to the assumption that the option holder is independent of the underlying uncertainty, it is reasonable to suspect that project management impacts the value real option.

Conceptual Hypothesis Statement

Figure 3 shows the hypotheses statements. Initially, we define the conceptual hypotheses which are later broken down into parts A & B for testing purposes.

H: Increased project management reduces real option value.

H1: Increased project management reduces the value of real options by reducing the variance of the exercise signal from the asset.

H2: Increased project management reduces the value of real options by reducing the difference between conditions for exercising the option and the mean exercise signal from the asset.

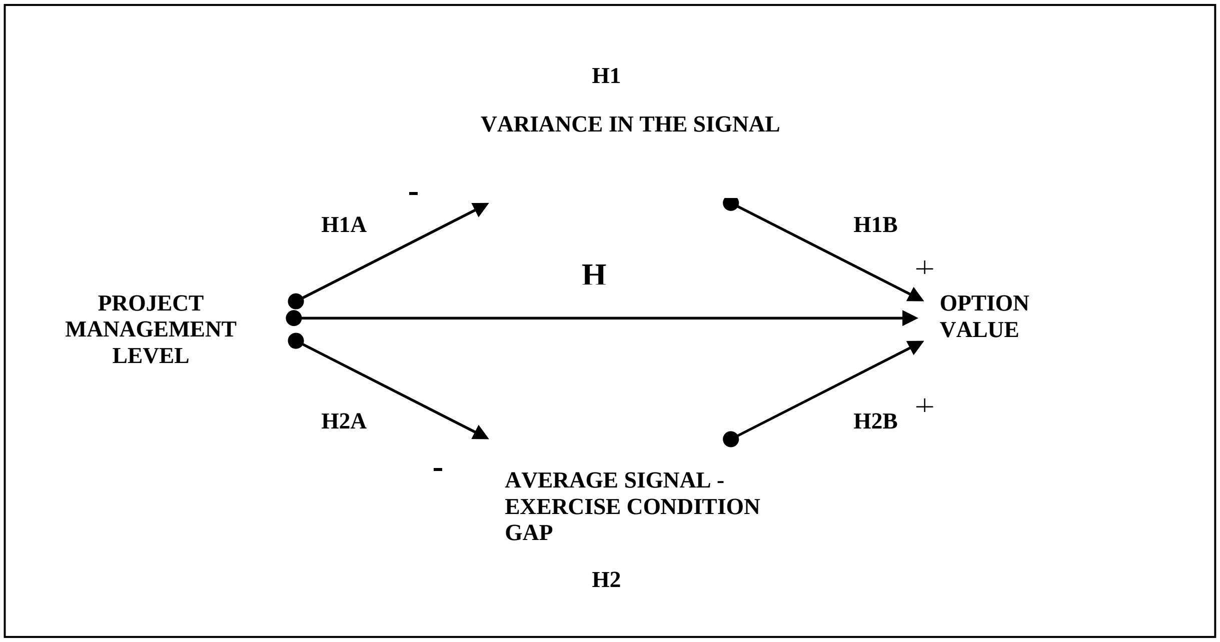

Fig. 3. Conceptual hypotheses

Fast Managed Projects

A fast project is a project that gets completed before the penalty deadline is reached as reflected in Figure 4. The Poor and Moderately managed projects finish after the Good managed projects. As can be seen from the figure, the variance of the project with Good management is less than that of the Poor and Moderately managed project.

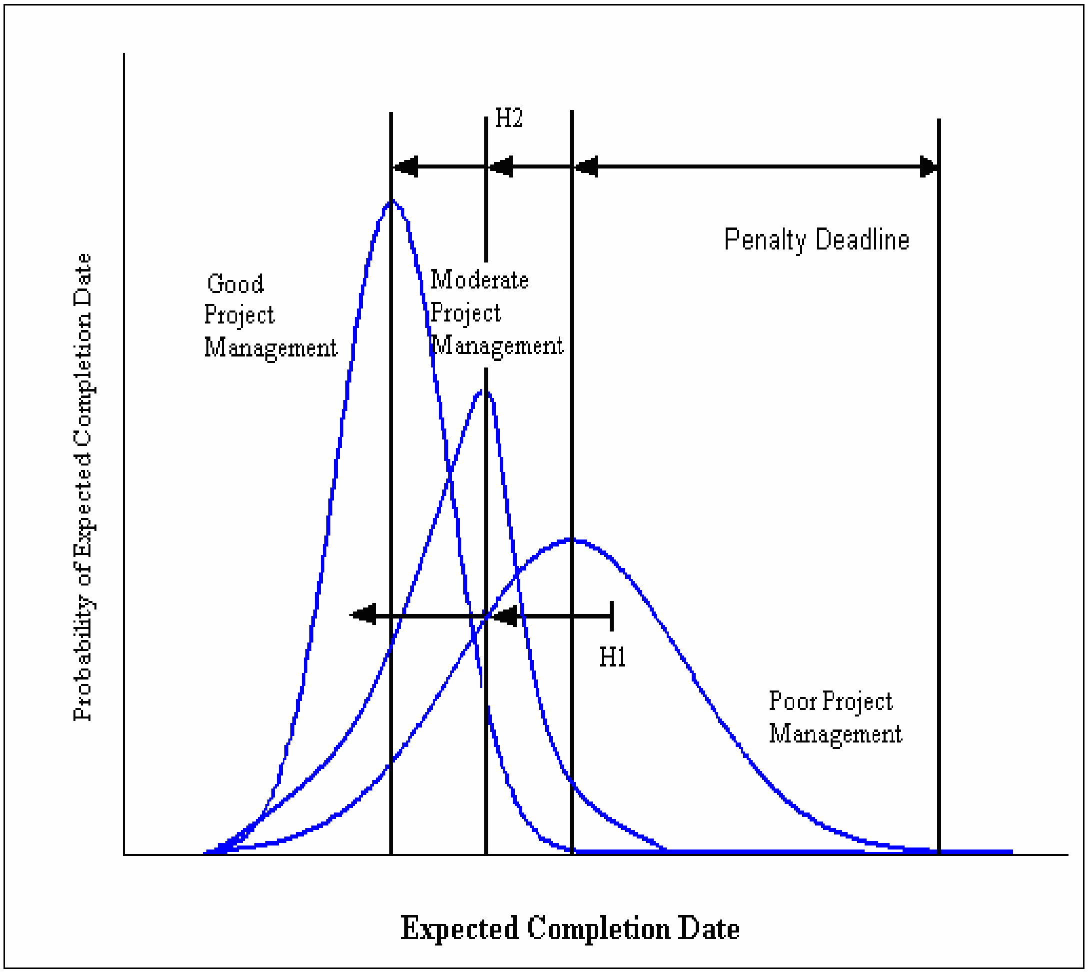

Fig. 4. Hypothesized effects of project management on forecasted completion dates (fast projects)

Slow Managed Projects

A slow managed project, is a project that gets completed after the penalty deadline is reached, as reflected in Figure 5. The Poor and Moderately managed projects finish after the Good managed projects. As can be seen from the figure, the variance of the project with Good management is less than that of the Poor and Moderately managed projects.

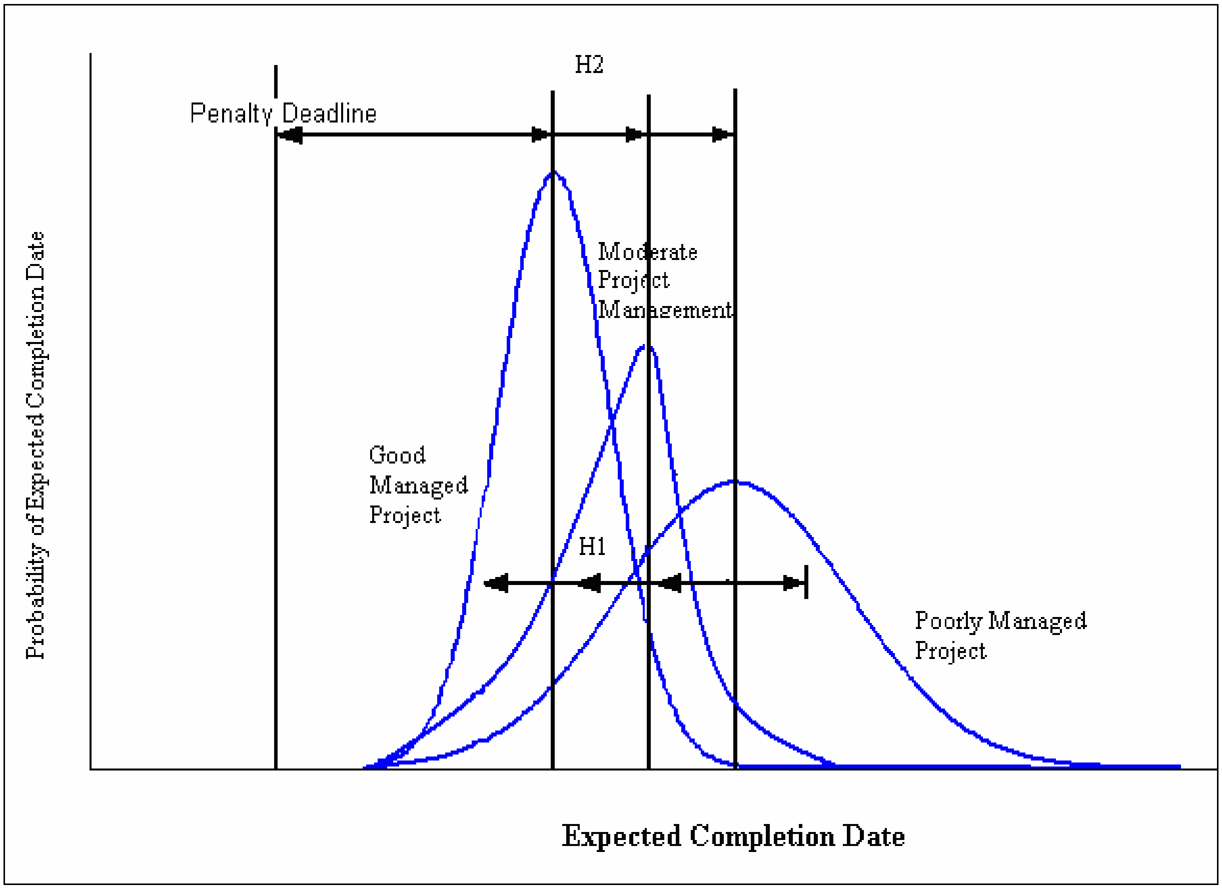

Fig. 5 Hypothesized effects of project management on forecasted completion dates (slow projects)

Operationalyzing the Hypotheses for Testing

The hypotheses are tested by modeling the hypothetical case of outsourcing for concrete work. The idea is to use the concrete outsourcing project to test the hypotheses. This is how the hypotheses will be operationalized for testing. The project needs to be completed by the deadline otherwise the project manager will be responsible for the penalty. The project manager has three alternatives:

- First is to outsource concreting to sub-contractor A (with constrained productivity) without any option, a rigid strategy

- Second is to outsource concreting to sub-contractor B (with unconstrained productivity) without any option, a rigid strategy
- Third is to outsource concreting to sub-contractor A but keep the option open to reverse the decision in favor of sub-contractor B (with unconstrained productivity) that is a flexible strategy

In any case, the project manager has the authority to decide the resource allocation policy for both the sub-contractors. The measure of project performance is the project duration and the project cost. For the given construction project, there are three levels of project management, as will be explained in the following pages. The behavior of the system changes with changing level of resource management and this directly affects the forecasting of the completion date. The option will be exercised due to a trigger. In this case, the trigger is pulled if at any given time, the forecasted completion date exceeds the deadline of the project. Thus, the exercise signal here is the forecasted completion date. The variance in the exercise signal will be affected as the level of project management changes. Hence, it will be interesting to know how the option value changes with a varying exercise signal. Similarly, if the difference between the exercise conditions and the mean exercise signal is considered, the changes in the option value can be related to it. Thus, the suspicion that project management impacts the value of real options could help answer the research question.

The project dynamics are captured by a system dynamics model. The model allows three levels of project management.

- Poor project management
- Moderate project management
- Good project management

The level of project management is reflected in the quality of resource allocation by the management. Poor project management is modeled with a static resource allocation policy; Moderate project management is modeled with a Myopic resource allocation policy while Good project management is modeled with a Foresighted resource allocation policy (Joglekar, Ford 2002). As the quality of resource allocation improves, the project is being managed better. Table 4 lists the nomenclature of project management for different cases for hypothesis testing.

Table 4. Nomenclature for Hypotheses on Option Values and Levels of Project Management

Subscript	Level of Project Management	Symbol	Standard Deviation of Exercise signal	Average Forecasted Lateness	Option Value
P	Poor Project Management	MP	σ S-P	μPL-P	VP
M	Moderate Project Management	MM	σ S-M	μL-M	VM
G	Good Project Management	MG	σ S-G	μL-G	VG

Figure 6 shows a more specific example of the causal basis for the hypotheses. The hypotheses are based on causal reasoning about the drivers of project progress and option values. The level of project management directly affects the project behavior. The behavior of the project determines the forecasted completion date which is the exercise signal. The option to reverse outsourcing will be exercised if at any given time the average forecasted completion date crosses the deadline for the project. The frequency of exercising the option will be determined over a number of simulations.

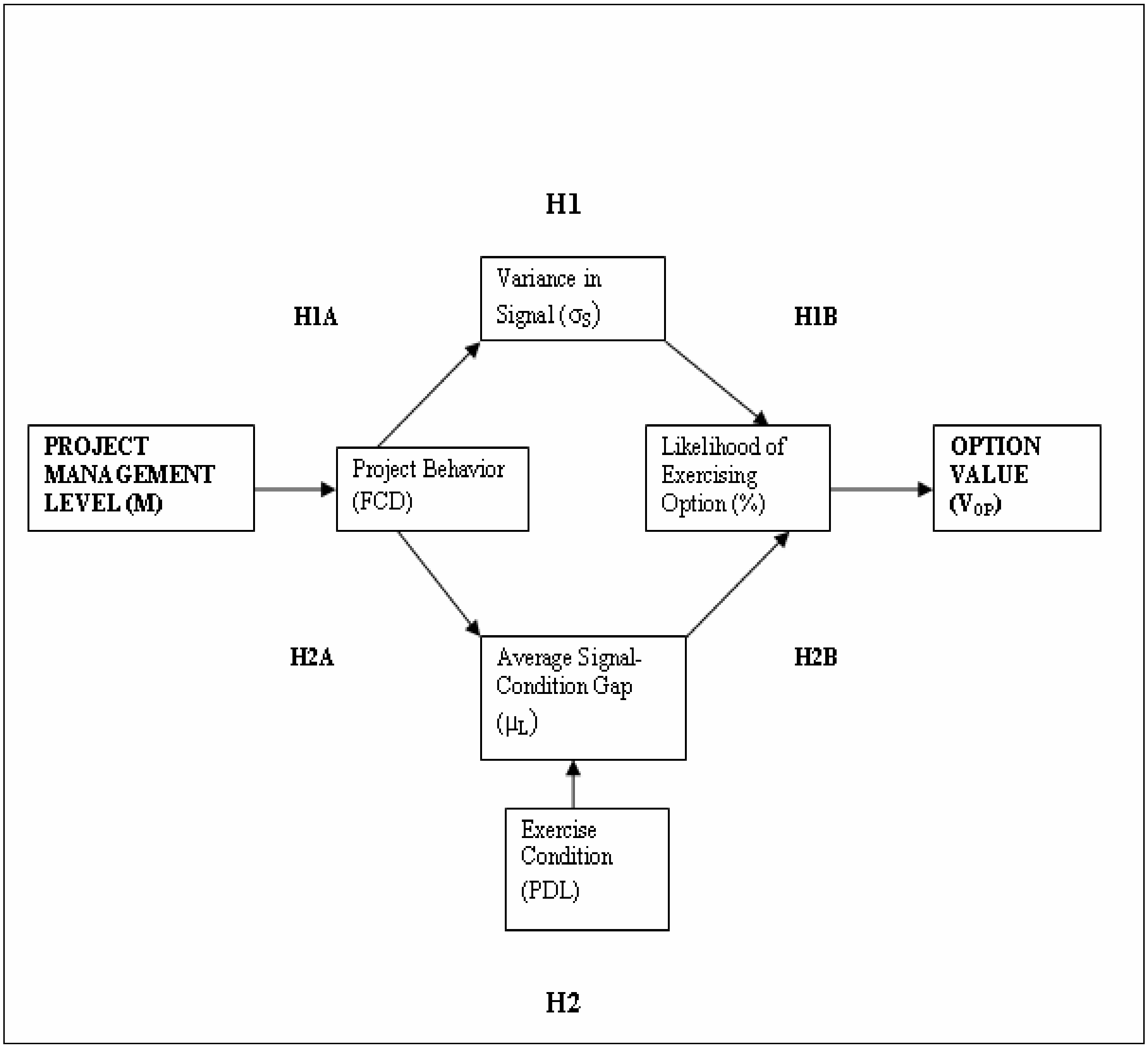

Fig. 6. Detailed conceptual hypothesis diagram

The average forecasted completion date and NPV of the project can be obtained from the model directly. The mean lateness of the project is calculated as the difference between the average forecasted completion date and the penalty deadline (89 weeks). Table 5 relates the conceptual hypothesis parameters to the operational hypothesis parameters.

Table 5. Operational Parameters of Hypotheses

Conceptual Hypotheses Parameter	Operational Hypotheses Parameter	Operational Hypotheses Parameter Symbol
Project Management Level	Project Control Lever 0 for Poor Project Management 1 for Moderate Project Management 2 for Good Project Management	MP MM MG
Project Behavior (Exercise Signal)	Smoothed Forecasted Completion Date	FCD
Variance in Exercise Signal	Average Variance over a project in Forecasted Completion Date	σ S
Average Signal Exercise Condition Gap	Forecasted Lateness (FCD – PDL)	µL
Likelihood of exercising option	Percent Projects in which option is exercised.	-
Exercise Condition	Penalty Deadline	PDL
Expected Option Value	NPV of the Project With Option - NPV of the Project Without Option	VOP

All measures are averaged across many possible project scenarios to reflect project uncertainties. This averaging is not reflected in parameter names for clarity. “Average” in the table above refers to averaging within individual projects.

The decision rule is that if the forecasted completion date exceeds the penalty deadline and the option is available, it will be exercised provided the project is not yet complete.

Pull Trigger = Option Availability Flag*IF THEN ELSE (Average Forecasted Completion Date>Deadline: AND: Exercise Trigger=0, 1/TIME STEP, 0) (1)

Operational Hypothesis Statements

H: Improved project management reduces real option value.

H1A: As project management improves, the variance of forecasted completion date decreases.

$\sigma S\text{-}G < \sigma S\text{-}M < \sigma S\text{-}P$ (2)

H2A: As project management improves, the mean forecasted lateness decreases.

$\mu L\text{-}G < \mu L\text{-}M < \mu L\text{-}P$ (3)

H1B: As variance in the forecasted completion date decreases, the value of real options to reverse outsourcing decreases.

$VP > VM > VG$ (4)

H2B: As the mean forecasted lateness decreases, value of real options to reverse outsourcing decreases.

$VP > VM > VG$ (5)

Data Requirements

To test the hypotheses, the following data is required:

- Project management level
- Forecasted completion date at each time step (to calculate variance in signal and average signal value)
- NPV of project with option (to calculate expected option value)
- NPV of project without option (to calculate expected option value)
- Deadline (to calculate average signal condition gap)

Data Collection

The required data was collected by simulating the real options model built in VENSIM (software used for simulation). For each treatment (project management level) the model was simulated for 100 runs with option available and 100 runs without option being available. In order to calculate mean and standard deviation of the average forecasted completions date, data was collected at every time step (0.125 weeks).

V. RESEARCH APPROACH AND DESIGN

Approach

System dynamics offers a project model which appears to reflect the real experiences of projects. The interrelationships between the project's components are more complex than is suggested by the traditional work breakdown structure of project network. An alternative view of the project is offered by system dynamics which concentrates on the whole project. The particular strength of system dynamics is that the interactions between different parts of the system can be examined, enabling an understanding of why things happen as they do and how one part of the system is likely to affect another part (Sterman 2000). To understand the impacts of management problems, system dynamics focuses on how project performance evolves in response to interactions between managerial decision-making and the development process (Ford and Joglekar 2004). A system dynamics model that reflects the real options approach is developed and is described in Section VI.

The model was simulated for different levels of project management keeping the strategies rigid as well as flexible. The data obtained from the simulations was analyzed using Excel. The following section describes the experiment design in detail.

Experiment Design

Three levels of project management are reflected in the quality of resource allocation in each case. For Poor project management, the resources are allocated simply by dividing them into three parts to take care of the three work requirements, namely, Quality assurance (QA), Initial completion (IC) and Rework (CH - change work). For example in the model, resource allocation for No Completion Work Required

= (1/3) = 33.33%

Thus,

MP IC Work Required = 33.33% (6)

MP QA Work Required = 33.33% (7)

MP CH Work Required = 33.33% (8)

where, MP is Poor (static) resource management

Moderate project management is modeled with a Myopic resource allocation policy considers only the current backlog. According to Ford and Joglekar (2004) common resource allocation policies allocate the same fraction of available resources to each activity as the fraction of total demand for resources created by the current backlog of work for that activity. For example, the allocation to QA is:

Resource Fraction M(M) QA = QA Backlog/ Total Backlog (9)

where, MM is Myopic resource management

Based on the above equation, the work required is

MM QA Work Required = QA Backlog (10)

Similarly for IC and CH, the work required is

MM IC Work Required = IC Backlog (11)

MM CH Work Required = CH Backlog (12)

This resource allocation policy however does not account for future demand of resources. Good project management is modeled with a Foresighted resource allocation policy that takes into consideration the current backlog as well as the future demand. A different Foresighted resource allocation policy model was proposed by Ford and Joglekar (2002) using system dynamics to consider future demand of resources and thus improve the resource allocation policy. The equations therefore are:

MF IC Work Required = IC Backlog (13)

MF QA Work Required = (QA Backlog + IC Backlog + CH Backlog) (14)

MF CH Work Required = (CH Backlog + QA Backlog * Iteration Fraction) (15)

where, MF is Foresighted resource management

The productivities depend on whether the work is being done in-house (in which case the productivity is assumed to be higher) or has been outsourced (in which case the productivity is assumed to be lower). The uncertainty lies in the productivities for Initial completion, quality assurance and the rework. The uncertain conditions are defined by a random normal function that generates normal distribution. The common resource productivity which is the uncertainty, depends on the common mean resource productivity and the coefficient of variation (= standard deviation / mean) that describes the size of uncertainty. A constant 40% coefficient of variance was assumed to keep the model simple.

100 project scenarios were simulated for each project management level (Poor, Moderate and Good) with options available or unavailable and the resulting data was averaged across the projects. The real option value is calculated from the NPV of project with rigid and flexible strategies as follows:

$$VOP = VF - VR \quad (16)$$

VR = NPV of the project without option.

VF = NPV of the project with option.

Hypothesis 1A:

H1A: As project management improves, the variance of forecasted completion date decreases.

$\sigma S\text{-}G < \sigma\ S\text{-}M < \sigma\ S\text{-}P$

To test hypothesis 1A, the forecasted completion date was used to calculate the standard deviation and averaged for each simulated project management condition at every 0.125 weeks (Time-step). The standard deviation values for each project management condition are plotted against the level of project management to obtain results.

Hypothesis 2A:

H2A: As project management improves, the mean forecasted lateness decreases.

$\mu L\text{-}G < \mu L\text{-}M < \mu L\text{-}P$

To test hypothesis 2A, the mean of the forecasted completion date was calculated (for a single run) and used to calculate forecasted lateness. The mean value for a 100 such means value was calculated. This value represents the mean of the forecasted completion date for each of the corresponding three levels of project management. These values are plotted against the level of project management to obtain results. In order to obtain the mean forecasted lateness, the deadline (89 weeks) was subtracted from the mean value of forecasted completion date for every run.

Hypothesis 1B:

H1B: As variance in the forecasted completion date decreases, the value of real options to reverse outsourcing decreases.

VP > VM > VG

To test hypothesis 1B, the NPVs of Project with and without option were obtained for each run using Equation (16). The standard deviation of the average forecasted completion date was calculated for each run as was done for testing H1A. All the cases where there was an option value were sorted out and their corresponding standards deviation values were obtained. Some of the runs did not have an option value because the option had not been exercised for those runs. A graph of Option value versus standard deviation was plotted for each level of project management.

Hypothesis 2B:

H2B: As the mean forecasted lateness decreases, value of real options to reverse outsourcing decreases.

VP > VM > VG

To test hypothesis 1B, the forecasted completion date and the NPV of Project with and without option were obtained for each run. All the cases where there was an option value were sorted out and their corresponding Mean Forecasted Lateness values were obtained. Some of the runs did not have an option value because the option had not been exercised for those runs. A graph of option value versus mean forecasted lateness was plotted for each level of project management.

VI. THE MODEL

The model assumptions identify the scope of the model. The model is based on the following assumptions:

- The model represents a single project.
- Uncertainty exists in the resource productivities.
- The decision to outsource is reversible until the maximum exercise date is reached and the project is not yet completed provided the option switch is on.
- The unconstrained in-house common resource productivity for sub-contractor B is greater than that for the constrained out-sourced resource productivity for sub-contractor A. However there is a cost for reversing the decision which is reflected by the exercise cost.
- The exercise cost is always less than the value of the underlying asset.
- The maximum resources available in terms of crew are ten and each crew is made up of a hundred team members.

Structure

The model consists of five subsystems as shown in the Figure 7 below. These are:

- Project Sector
- Resources Sector
- Forecasting Sector
- Cost Sector and,
- Options Sector

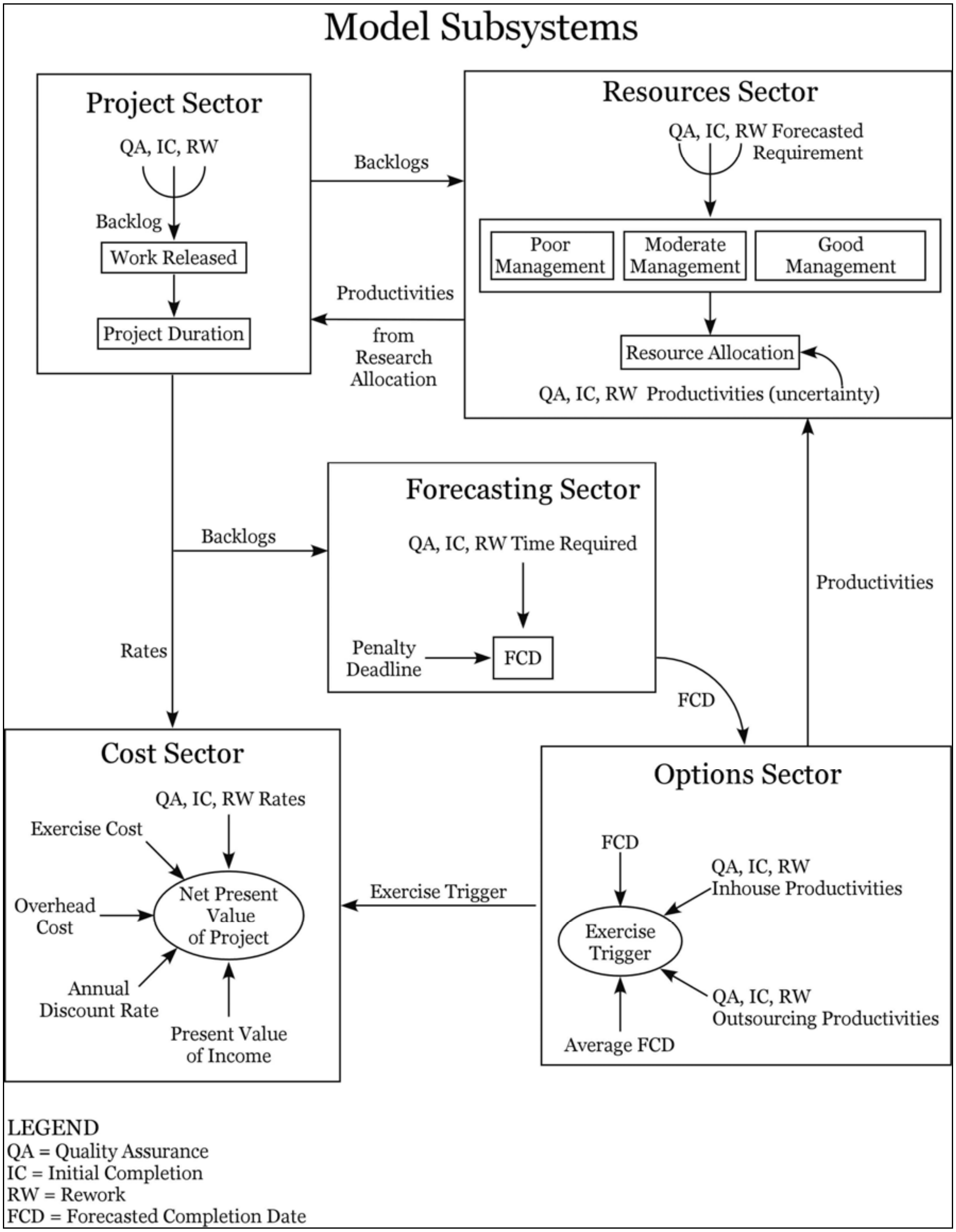

Fig. 7. Model subsystems

The project develops as the work flows from initial completion through quality assurance and finally rework if required, in the project sector. The work that gets completed and also passes through quality assurance, adds up to work released until finally the project scope is reached. The project duration is also calculated in this sector. The productivities (depending on the resource allocation policy of the management) from the resources sector influence the project duration. The backlog from the project sector is an input to the resources sector, to determine the resource demand and hence the resource allocation policy.

The backlogs and rates of initial completion, quality assurance and rework changes from project sector are the inputs to the forecasting sector that determines the forecasted completion date using this data and a penalty deadline. The rates from the project sector are also an input to the cost sector that calculates the weekly cost of the project. The final NPV of the project is determined using the accumulated project cost and the net value of income over the duration of the project.

Depending on the in-house or out-sourcing productivities, and the forecasted completion date from the Forecasting sector, the option sector gives information about the exercise trigger. The exercise trigger also serves as an input to the cost sector. The policy of with or without option can be controlled in the options sector.

Project Sector

The project sector reflects the flow of work from one stage to another (Figure 8). The project scope is 200 work packages and it defines the scope and size of the project. The work is initially in the completion stage from where it is subjected to quality assurance. The iteration fraction is 40% and is given by:

Iteration Fraction = Probability of a Change being needed * Probability of a Needed Change being discovered (17)

The work that needs to be changed accumulates as the change backlog from where it again goes through completion and quality assurance. The work that does not need to be changed is released and the project duration required is calculated.

The equations for work flow are as follows:

IC rate = MIN(Completion Resource Rate, IC Backlog/IC process duration) (18)

QA rate = MIN(QA Backlog/QA Process Duration, QA Resource Rate) (19)

CH rate = MIN(CH Backlog/ CH Process duration, CH Resource Rate) (20)

The resource rates are obtained from the resources sector.

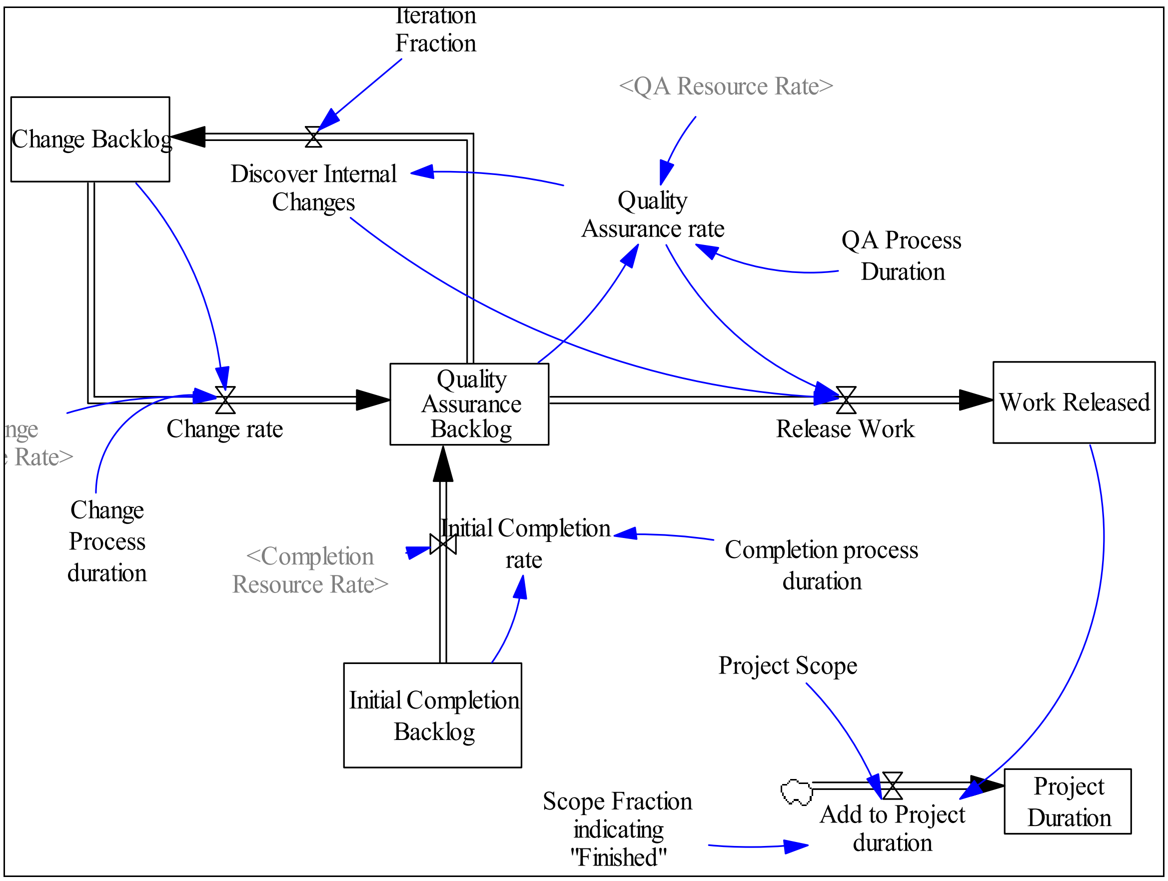

Fig. 8. Project sector

Resources Sector

The resources sector (Figures 9, 10 and 11) is used for resource allocation and to obtain resource rates. The forecasted completion resource demand, forecasted quality assurance resource demand and the forecasted rework resource demand, together give the total resource demand Figure 9.

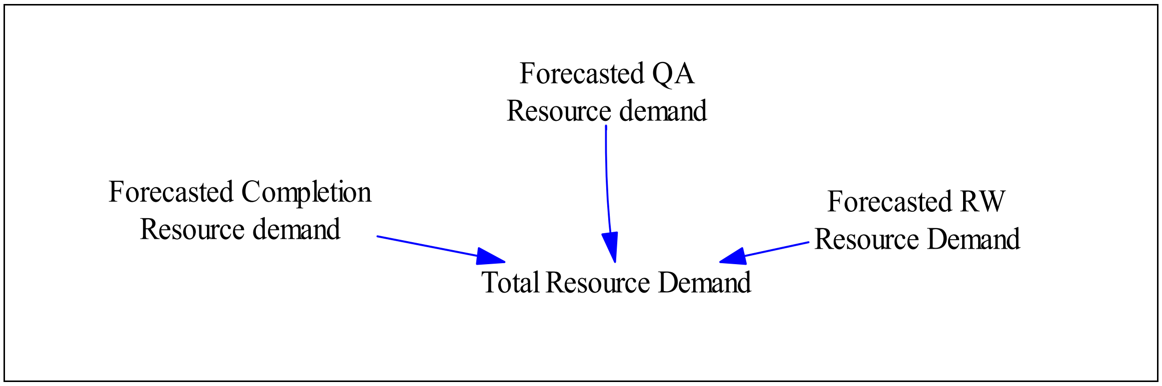

Fig. 9. Total resource demand

Each of the forecasted resource demands is calculated based on the management policy and the work requirement as shown in Figure 10.

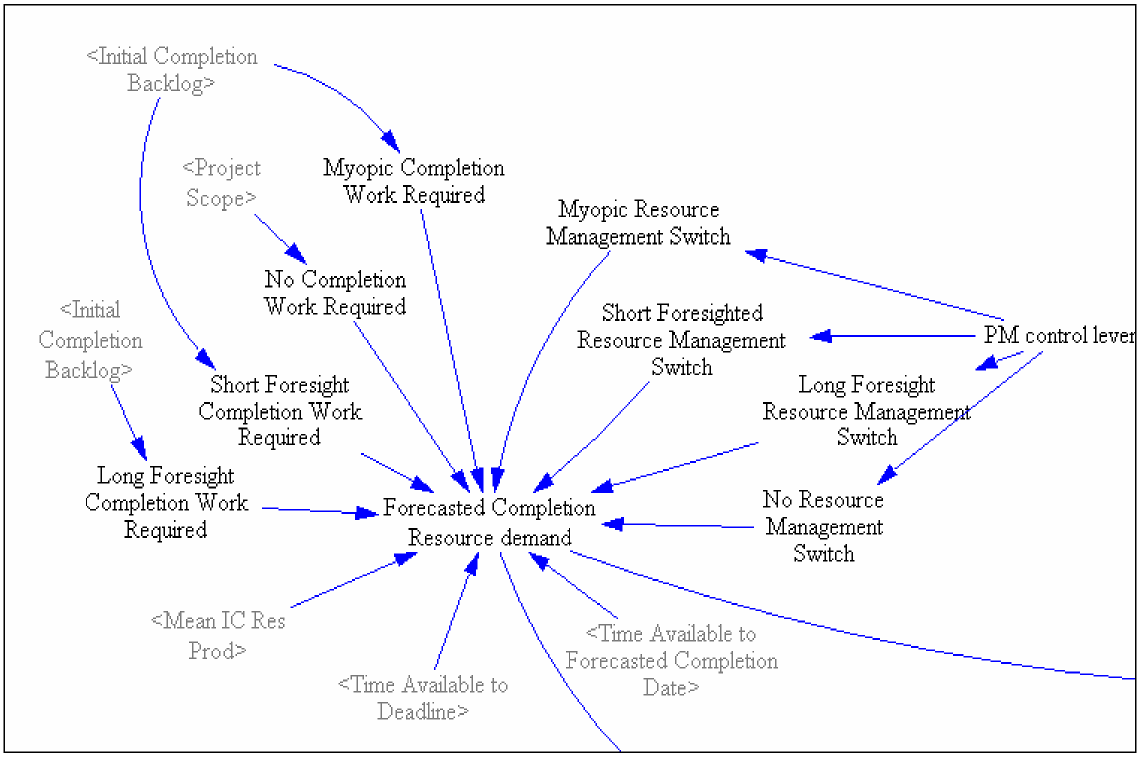

Fig. 10. Forecasted completion resource demand

The forecasted completion resource demand equation is as follows:

Forecasted IC Resource demand = ZIDZ(((M(N) Switch *No IC Work Required)+ (M(M) Switch*Myopic Completion Work Required)+(M(F) Switch*Short Foresight Completion Work Required)

(21)

The switch for each management policy is controlled by a PM control lever that gives the freedom to choose a different policy as required.

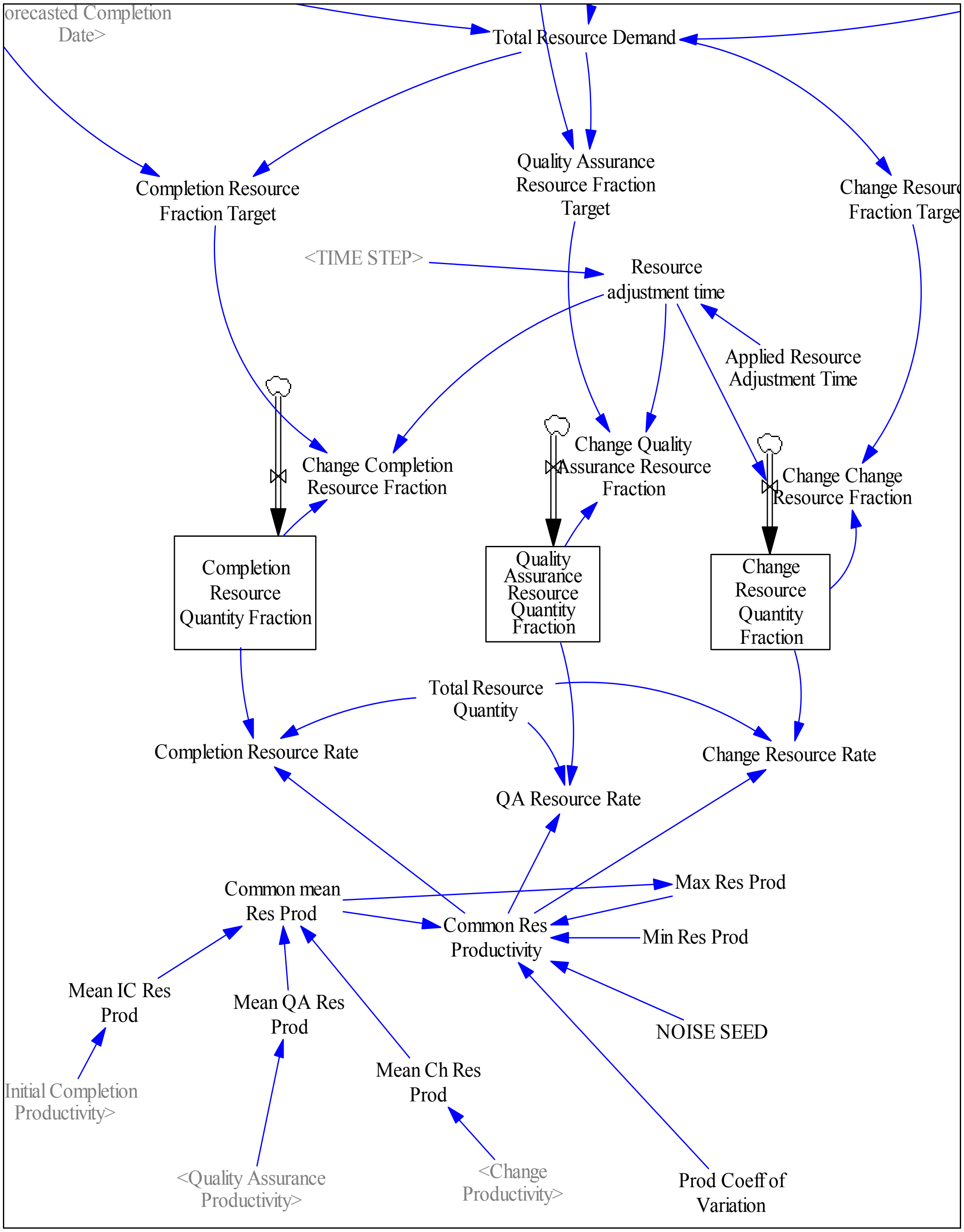

Fig. 11. Resource allocation

The initial completion, quality assurance and change productivities shown in Figure 11 are obtained from the options sector and the common resource productivity is calculated. This productivity is used for all the work flow equations.

The resource rates are calculated by multiplying the total resource quantity with change resource quantity fraction and common resource productivity. A resource adjustment time of 30 weeks has been applied to represent the actual time required to reshuffle or allocate resources.

Forecasting Sector

The project completion date is the week in which all work gets completed and is released. The project manger is watching the whole project and based on his/her experience and knowledge forecasts the completion date. In this case the basis of forecasting is the time required and the elapsed time for forecasting project completion.

The forecasting sector (Figure 12) is used to obtain the forecasted completion date. The forecasted completion date is obtained by adding the elapsed time for forecasting completion ("Time" variable in the model) to the time required to complete the remaining work packages. The time required is obtained by adding the initial completion, quality assurance and change times required for completing the work packages that have not been released. The deadline is set to 89 weeks. The forecasted completion date is the input to the options sector used to determine if the option is to be exercised or not.

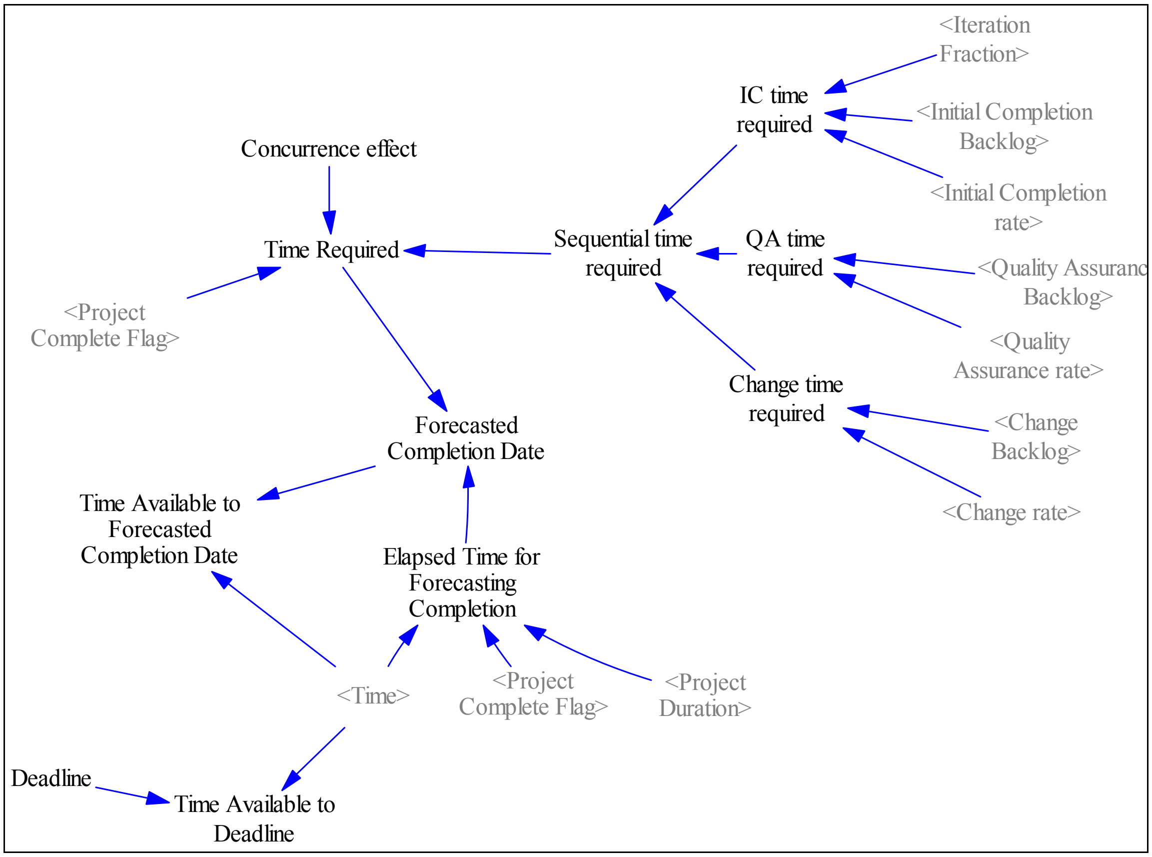

Fig. 12. Forecasting sector

Options Sector

The options sector (Figure 13) is used to reflect the real option in the project. The sector analyses the input (average forecasted completion date) to the exercise trigger and depending on the set condition decides whether or not to pull the trigger.

Pull Trigger = Option Availability Flag*IF THEN ELSE (Average Forecasted Completion Date>Deadline: AND: Exercise Trigger=0, 1/TIME STEP, 0)

(22)

The trigger can be pulled only if the option switch is on, that is, the strategy is flexible to have an option. The trigger is pulled if the average forecasted completion date exceeds the deadline, provided the project is not yet completed. A simple first order adjustment is used to calculate the average forecasted completion date.

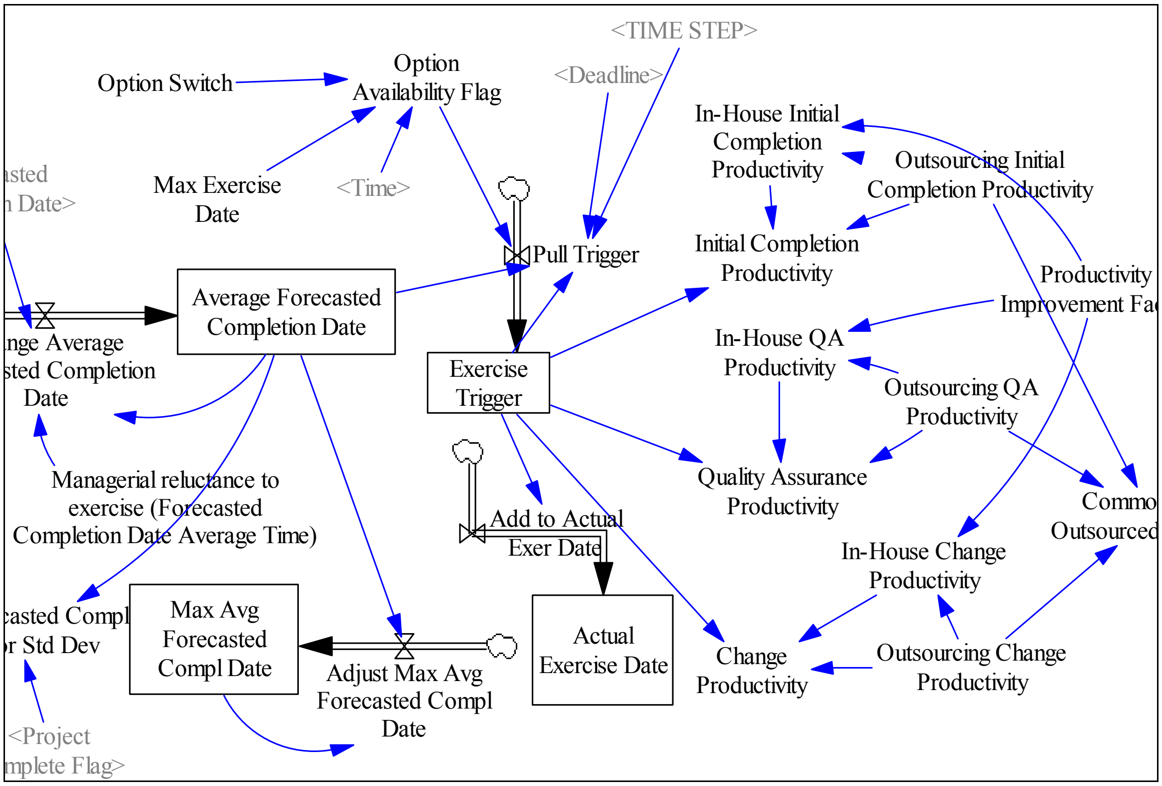

Fig. 13. Options sector

Cost sector

The cost sector (Figure 14) uses inputs from the project sector and the options sector. The unit cost is set per work package for initial completion, quality assurance and rework. This unit cost is multiplied by the rate of completion of each of the three activities to get their respective weekly costs. In addition there is a weekly overhead cost. An exercise cost is applied only when the option is exercised. The total weekly project cost is then converted to its present value using the following equations:

Weekly Project Cost Present Value = Present Value Fraction*Applied Weekly Project Cost (23)

Present Value Fraction = EXP (-(Weekly Discount Rate*Time)) (24)

The present value of weekly costs accumulates over the project duration.

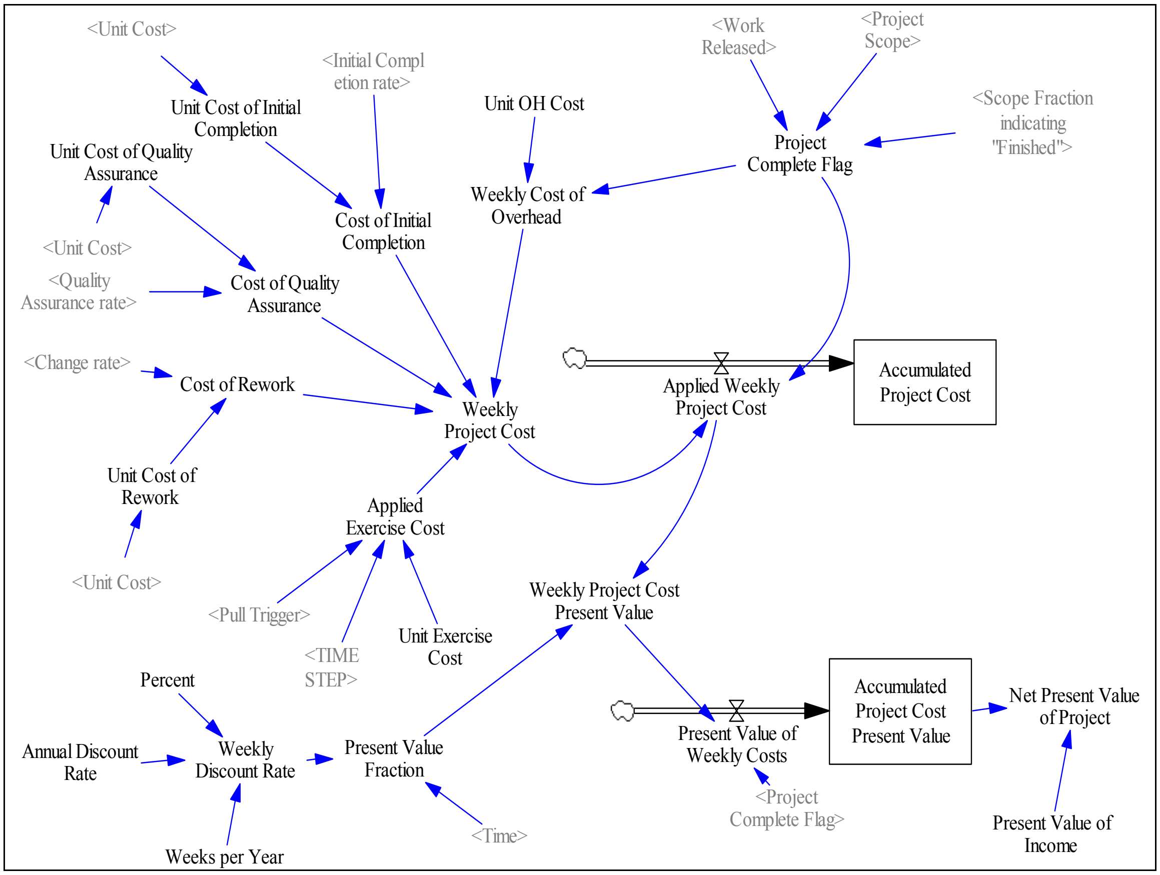

Fig. 14. Cost sector

The present value of income is the expected revenues from the project and the NPV of the project is calculated as:

Net Present Value of Project = Present Value of Income-Accumulated Project Cost Present Value (25)

The cost sector thus gives the NPV of the Project which is one of the most important data required.

Table 6 summarizes the sources of the data required from the model.

Table 6. Data Sources from Model

Data Required	Model Source
Project Duration	Project Sector
Project Management Level	Resources Sector
Average Forecasted Completion Date	Forecasting Sector
Actual Exercise Date	Options Sector
NPV of Project with and without Option	Cost sector

Base Case

The base case in the concrete outsourcing example is the one with moderate project management. Table 7 lists the variables that define the base case scenario. These variables are assumed based on historical data and the experience of the project manager. The base case assumes a 40% probability of rework. The project duration will vary according to the resource productivities. The base case will give good insight into the model behavior. It is necessary to know how the model behaves and how closely it resembles a project scenario in the real world.

Table 7. Base Case Variables

Variable	Value	Units
Productivity Coefficient of Variation	0.4	Dimensionless
Iteration Fraction	40%	Dimensionless
Penalty Deadline	89	Week
Total Resource Quantity	10	Crew
Discount Rate	10	Percent / Year
Applied Resource Adjustment Time	30	Week
Completion Process Duration	1	Week
Quality Assurance Process Duration	1	Week
Change Process Duration	1	Week

Table 7 (continued)

Variable	Value	Units
Managerial reluctance to exercise (Forecasted Completion Date Average Time)	3	Week
Maximum Exercise Date	150	Week
Outsourcing Change Productivity	1	WP/ (Week*Crew)
Outsourcing Completion Productivity	1	WP/ (Week*Crew)
Outsourcing Quality Assurance Productivity	1	WP/ (Week*Crew)
Project Scope	200	WP
Productivity Improvement Factor	1.1	Dimensionless
Unit Cost of Initial Completion	10	Thousand Dollars/WP
Unit Cost of Quality Assurance	10	Thousand Dollars/WP
Unit Cost of Rework	10	Thousand Dollars/WP
Unit Exercise Cost	100	Thousand Dollars/Week
Unit Overhead Cost	150	Thousand Dollars/Week
Concurrence effect	2	Dimensionless
Time Step	0.125	Week
Final Time	150	Week
Scope Fraction Indicating "Finished"	0.995	Dimensionless
Weeks per Year	52	Week
Present Value of Income	25000	Thousand Dollars

Flow of Work in the Project

The project will be complete when the phase scope is completed. The project sector includes the flow of work through the three stages of Initial completion, Quality assurance and Rework.

The initial completion backlog depends on the rate of initial completion. Hence it starts at 200, the project scope. Completion resource productivity is assumed to be 1, and this together with available resources and completion resource rate determine how fast work gets completed. The work that is completed goes for checking by the quality assurance department. After inspection, in this case, the amount of work that needs to be re-done is 40%. The rest of the work gets released. The work packages that need change get accumulated to form the rework backlog and this depends on the rate of quality assurance and the probability of rework. Hence, the change backlog has its' peak towards the end of the project.

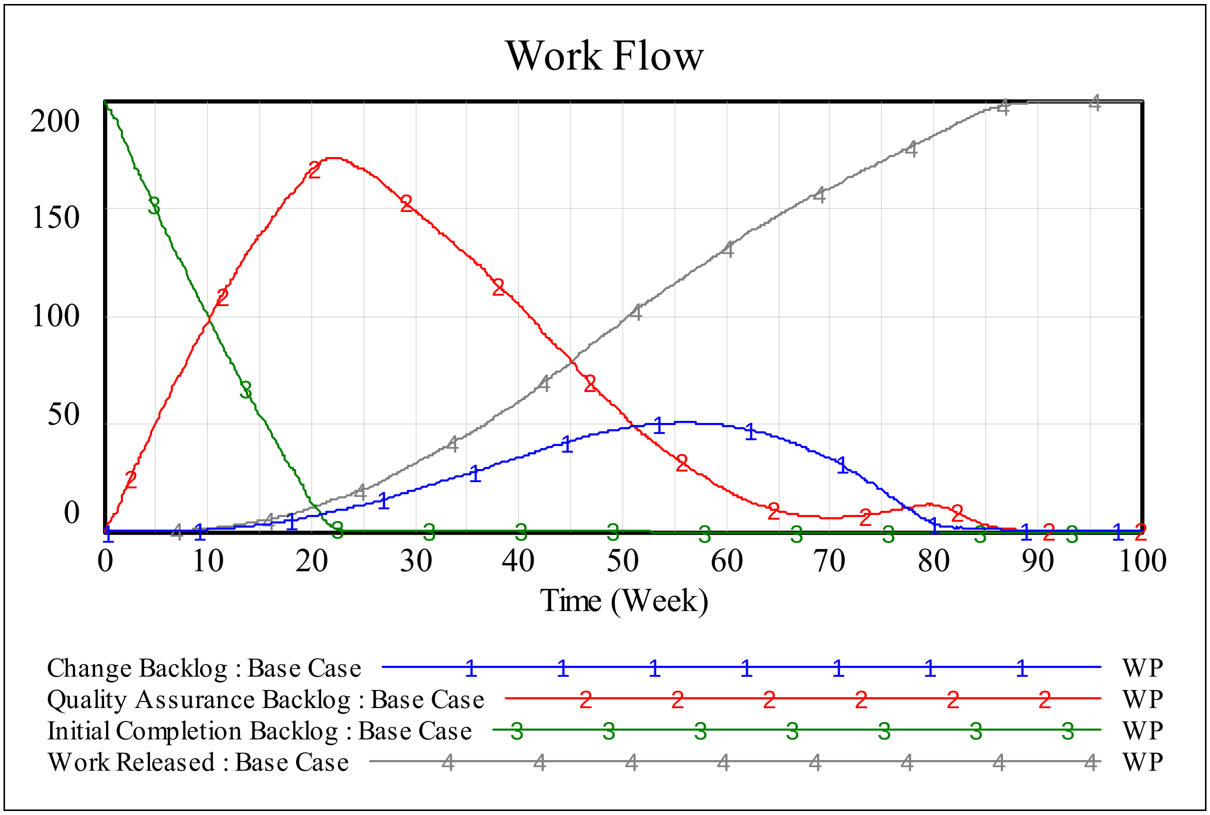

Fig. 15. Project work flow

At the beginning of the project no work has been done and therefore the initial completion backlog is 200. Figure 15 shows the flow of work through the project life. Since at the very beginning, no work has been completed, there is no work to be checked or changed and hence no work has been released. Gradually, as the project progresses, workload in the Quality assurance section of the project sector starts increasing. Here, some work that passes the quality assurance criteria is released (60% of the total work passes, since the probability of rework in the base case is 40%), whereas the remaining work goes back into the Rework backlog.

The work to be released gradually increases till all the work is released and the project is completed. The time in which the project gets completed in this case is 89 weeks.

Resources

The total resource demand is the sum of the QA resource demand, IC demand and the CH resource demand. Since no work is complete in the beginning, the demand for IC resources is at its maximum that is 2.25 crew (225 laborers). Since no work is done, there is no demand for resources for checking and changing the work at time = 0 (Figure 16). As work is completed the initial completion demand starts decreasing and quality assurance starts increasing and it reaches a peak almost at the end of initial completion. There is another peak towards the end of the project which can be attributed to a fluctuating change resource rate. The resource demand for work to be changed follows a similar pattern and its peak towards the end of the project, as expected. The total resource demand is given by the following equation:

$$\text{Total Resource Demand} = \text{Forecasted CH Resource Demand} + \text{Forecasted IC Resource demand} + \text{Forecasted QA Resource demand} \quad (26)$$

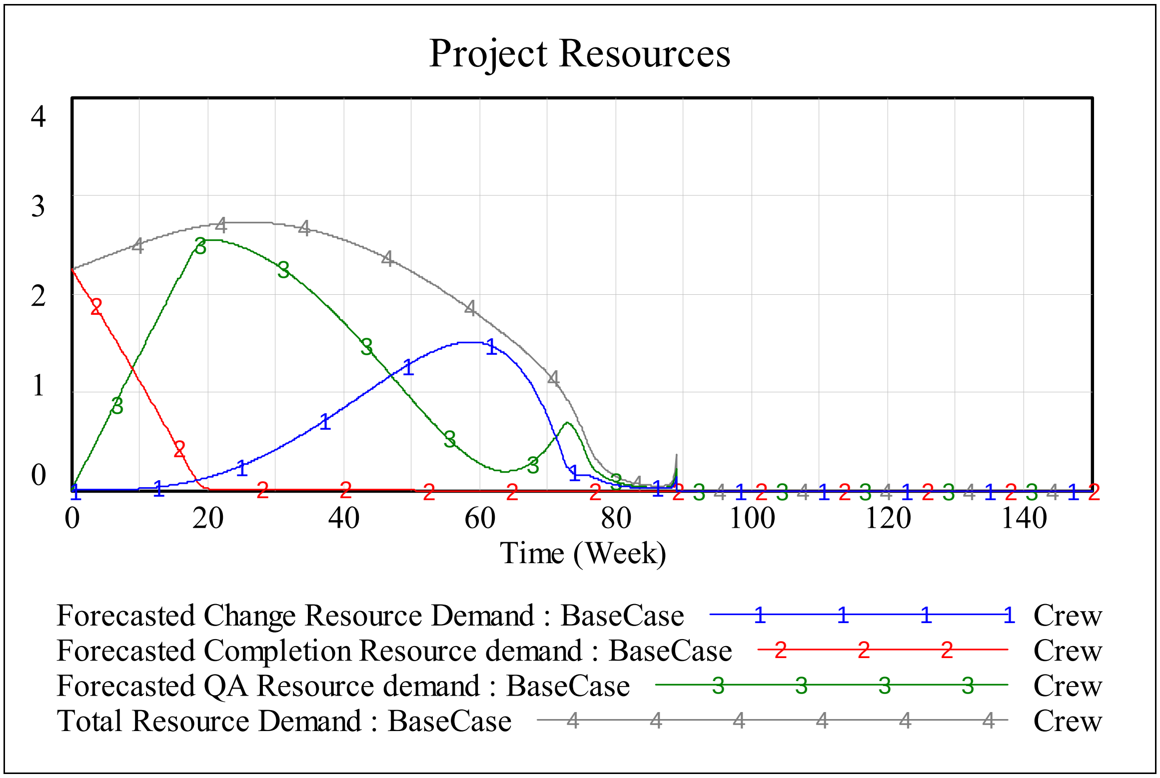

Fig. 16. Project resources

It decreases as the project nears completion and is zero at the end of the project when all the work including all rework is finally completed and released.

Project Forecasted Completion Dates

Time required depends on sequential time required which is an addition of IC time required, QA time required and CH time required. A concurrence effect equal to and acting in opposite direction as the iteration effect is used to calculate time required. Elapsed time is given as:

Elapsed Time for Forecasting Completion = IF THEN ELSE (Project Complete Flag=0, Time, Project Duration) (27)

As is seen from Figure 17, right at the beginning the project manager forecasts a completion date at 89 weeks which is the deadline. However, in the beginning, all the easy work is getting completed and there is "pseudo-productivity" which seems to be high. It means that the productivity appears to be high in the beginning. This causes the project manager to forecast an earlier completion. As the project progresses and rework starts coming into picture, the project manager anticipates a higher forecasted completion date. As the project gets ahead in full swing, and the project manager can forecast better and the fluctuations in the forecasted completion date reduce. The forecasting becomes more and more accurate as the project nears completion.

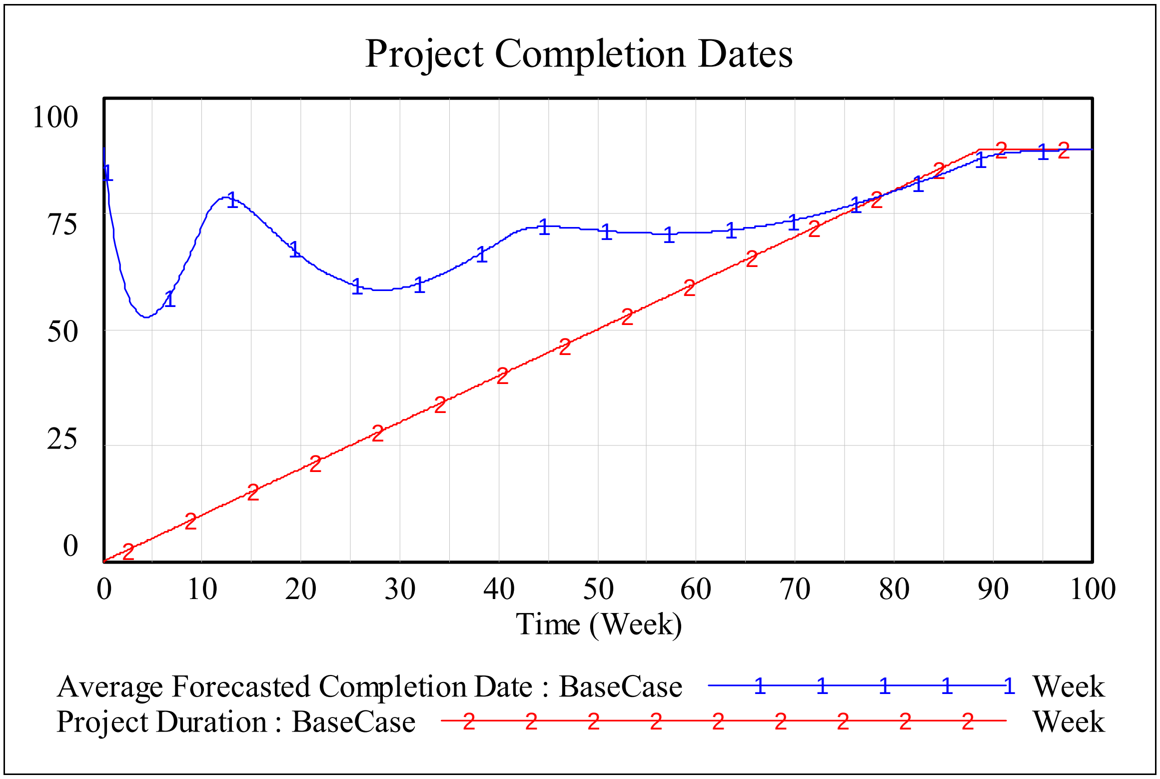

Fig. 17. Average forecasted completion date

Project Costs

Figure 18 shows the behavior of project costs over the life of the project. The accumulated project cost is calculated using equation 24, and the NPV of the project is calculated using Equation 25. The NPV is assumed to be $25 million, which is the present value of expected revenues from the project. As the project progresses, the accumulated project costs go on increasing and the NPV of the project goes on reducing, as is expected. The option is not exercised for the base case and hence, there is no applied exercise cost included in the graph.

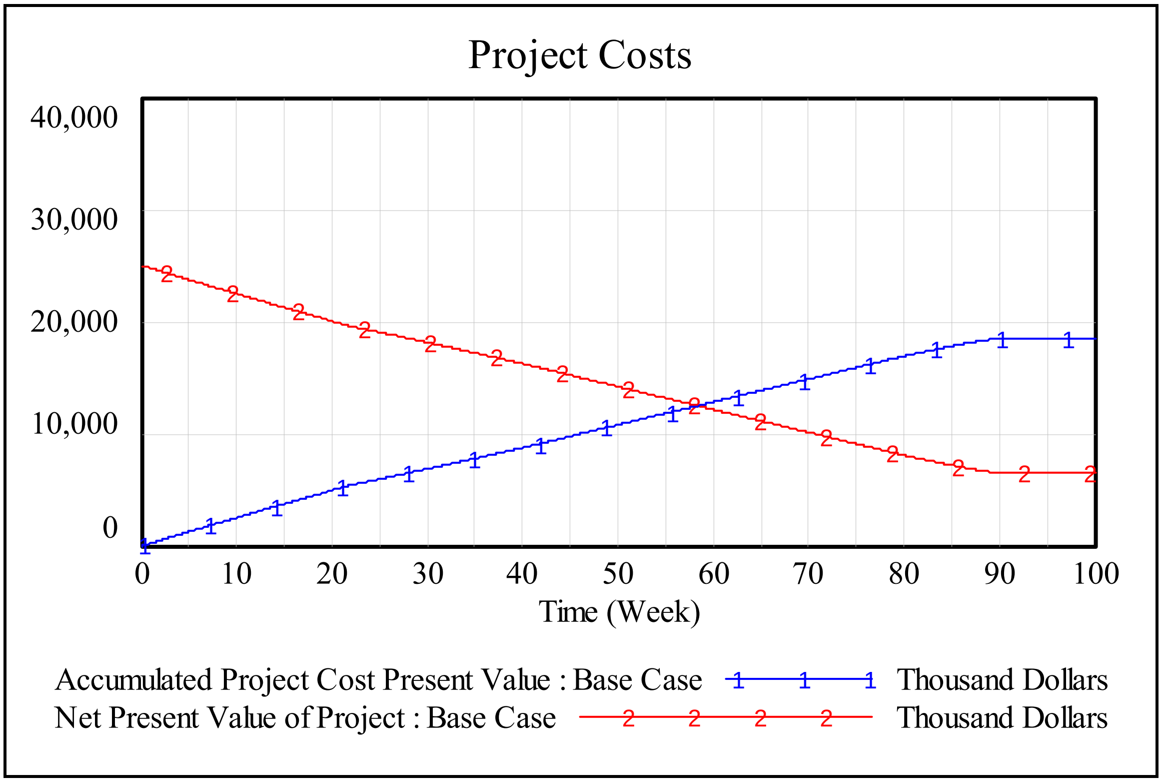

Fig. 18. Project costs

The graphs above show how the model behaves, and how closely it resembles a project in reality. In reality, as the project gets completed, the accumulated project cost will go on increasing till the project is completed. Also the NPV of the project goes on decreasing since it is calculated as the difference between the present value of expected revenues from the project and present value of the accumulated project cost.

Validation

Model testing is an integral part of developing useful models. A model is generally based on certain assumptions that make the model work as expected. However, for the model to be useful, it must fit historical data well enough and must work consistently with the real knowledge of the system. Sterman (2000) suggests twelve tests for an assessment of dynamic models. The following discussion answers the questions of what these tests are and how they will be used (or why, if not used) in this study.

Boundary Adequacy

The boundary adequacy tests help in defining the scope of the model. They confirm whether or not, the key factors determining the solution for the problem being modeled are endogenous. It is important to see the behavior of the model when the boundary conditions are relaxed.

In the model presented here, subsystem diagrams were created. The exogenous variables were identified and made endogenous wherever possible or changed significantly. The effect of this on the behavior of the model was studied.

Structure Assessment

According to Sterman (2000), structure assessment tests focus on the level of aggregation, the conformance of the model to basic physical realities such as conservation laws and the realism of the decision rules for the agents. The test helps in determining the contribution of each variable in policy making.

A direct check of all the equations was carried out and was useful to expose the heuristics assumed at each decision point. The model was checked for stocks becoming negative (that would not happen realistically). The following stock variables were checked for negativity:

- Accumulated Project Cost
- Accumulated Project Cost Present Value

- Actual Exercise Date
- Average Forecasted Completion Date
- Change Backlog
- Change Resource Quantity Fraction
- Completion Resource Quantity Fraction
- Exercise Trigger
- Initial Completion Backlog
- Maximum Average Forecasted Completion Date
- Project Duration
- Quality Assurance Backlog
- Quality Assurance
- Work Released Resource Quantity Fraction

Dimensional Consistency

Dimensional consistency is the basic test for all mathematical systems. The test not only uncovers any flaw in the equations, but also validates the understanding of the decision making process that is being modeled. For example, the forecasted demands depend on productivity, workload and time available. Once the equations for these are written, they must give the unit of forecasted demand in crew. Dimensional test of model equations was conducted using "unit check" from Vensim. It verifies that all model units in variables are consistent. Without the use of parameters having no real world meaning, the model should be able to exhibit dimensional consistency. This was done by inspecting the model equations for "dimensionless" variables.

Parameter Assessment

The model should reflect real world parameters. Hence it is important that each variable has a physical significance.

Each of these variables will have statistical estimation or judgmental estimation. Physical significance of each term is documented into the model. This reflects how close the model represents the real world systems. Each of the variables has been described in the model. A list of all the variables, their equations and description can be found in Appendix A.

Extreme Conditions

According to Sterman (2000), the robustness under extreme conditions means the model should behave in a realistic fashion, no matter how extreme the inputs may be. Reality checks need to be performed for the model. Simulating the model with extreme values of the following variables was performed:

- Annual discount rate: The value of this variable was made 0 and then 100 to see if there was any difference in the behavior. The model behaved in the same pattern as the base case, in either case.
- Applied Resource adjustment time: The applied resource adjustment time is assumed to be 30 weeks. This was changed from 0 to 89 (deadline) and the effects were studied. Project duration, which also depends on resource adjustment time, showed reasonable behavior at higher resource adjustment time. However, for resource adjustment time below 25, the project duration for Good management was greater than that for Moderate management policy. Therefore the use of 30 weeks is alright.
- Final time: Final time is the maximum time in which the project can get completed for any given case of the model. The final time was changed from 150 and to 20000 to test the model. This change did not affect the model behavior.
- Managerial reluctance to exercise (Forecasted Completion Date Average Time): A three week period is given to the project manager to make decision regarding reversing outsourcing. This period reflects the time taken to think, decide and implement changes by the project manager. Changing this period did affect the forecasted completion date to a certain extent.

- Present Value of Income: Changing the present value of income causes proportional changes in the NPV of the project, which is quite acceptable as it does not change model behavior.
- Project Scope: The current scope of the project is 200. Changing this to 100 or 1000 does not affect the pattern of the model. Only the numerical values change.
- Unit Costs: Changing the unit costs changes the total project costs. The only unit cost that cannot be changed beyond a certain limit is the applied exercise cost. This cost should always be less than the present value of income.

Integration Error

The numerical integration method and the time step used in simulation must not affect the results of the model. For most models of complex problems, where there are large errors from aggregation, miss-measurement, simplification, and lack of information, Euler integration suffices. For models of physical systems and for simple conceptual models, especially those involving oscillation, Runge-Kutta integration is probably preferred. Euler integration assumes that the rates computed at a given time are constant through the time interval (time step). In general, this is not likely to be true, and that is why Euler integration is not very accurate. To make the integration more accurate, the time step can be decreased. Difference Integration is the same as Euler Integration except in the recording of the results. Euler integration reports Levels and the values that result from those Levels, whereas difference integration reports the Level and the values that resulted in those Levels. Runge-Kutta integration is an extension of Euler integration that allows substantially improved accuracy, without imposing a severe computational burden. The idea is to step into the interval and evaluate derivatives. This is similar to shortening time step in Euler integration, but provides more accuracy with less increase in computation.

The model can be tested by changing the integration method from Euler to Runge-Kutta and by varying the time step.

Project Validation

Two types of validations are needed for the model. The first one is for the base case, in which the model is checked for project performance. As project management improves the project performance in terms of duration and cost improves. The model behavior was checked for the same using the base case.

The second validation is done for reliability of the model to reflect real options. The model should reflect the characteristics of real option components stated in Table 4. Figure 20 reflects the project durations for a flexible strategy in the project. The PM control Lever works as shown in Table 7:

Table 8. Project Management Controls

Project Management Level	Corresponding PM Control Lever
Poor Project Management	0
Moderate Project Management	1
Good Project Management	2

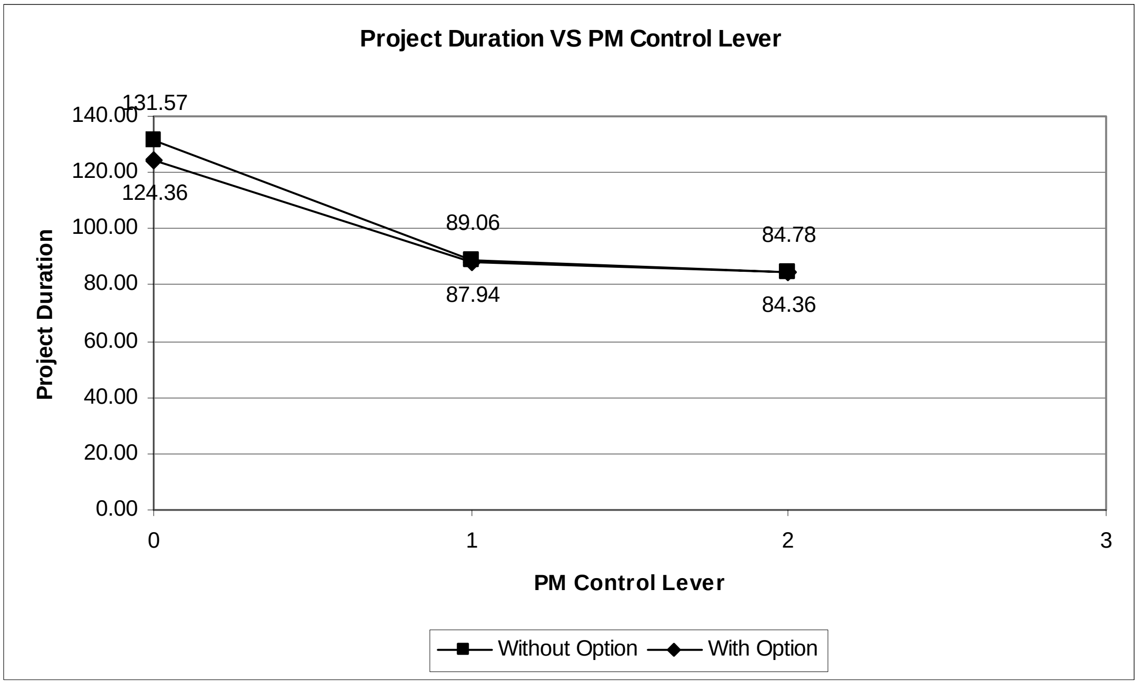

Fig. 19. Project duration validation

Figure 19 shows that as project management increases, project durations (for both with and without option projects) reduce. The project duration for project with option is usually lesser than that for a project without option because the project management improves causing increased productivity. Each of these project duration values is an average value that has been obtained by running 100 simulations for each case.

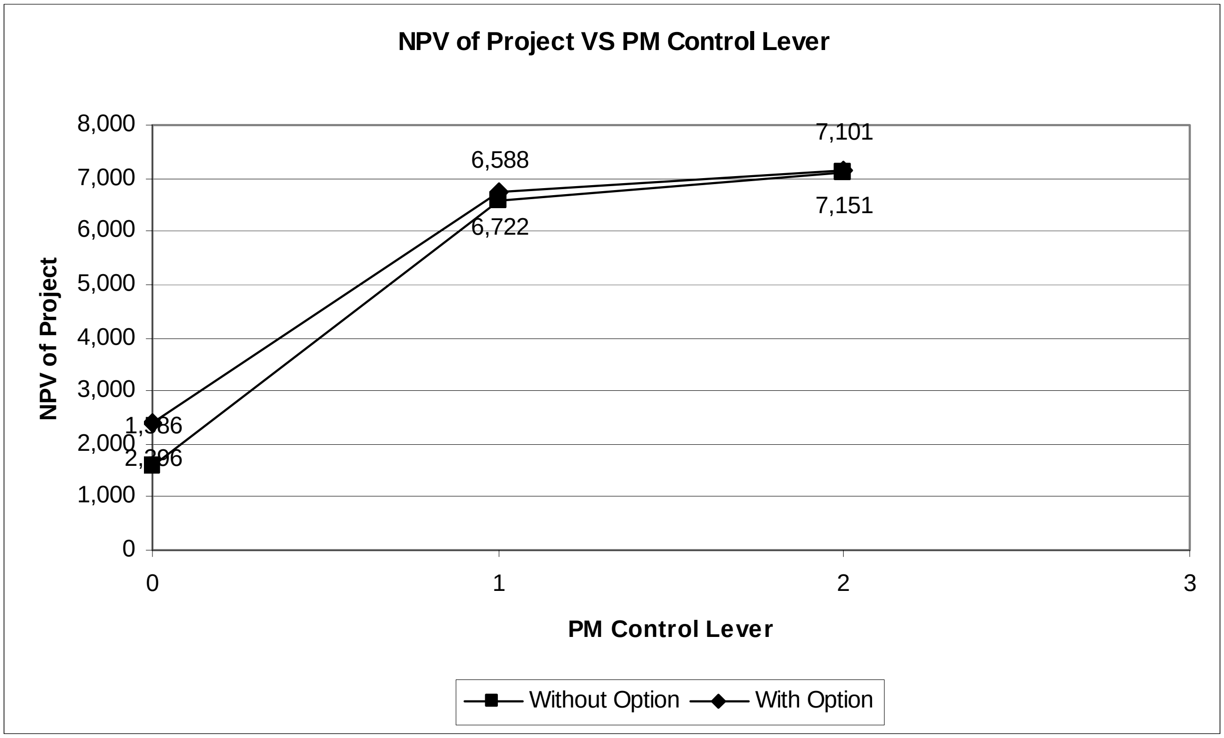

Fig. 20. Project NPV validation

Figure 20 shows that as project management increases, NPV of the project (for both with and without option projects) increases. The NPV of the project for project with option is always greater than that for a project without option since project management is improved. Each of these NPVs of the project is an average value obtained by running 100 simulations for each case.

The following graph, Figure 21, shows that as the level of project management increases, the frequency of exercising option significantly reduces. The frequency of exercising option has been directly obtained from the model for each case. This means that the option was exercised 8 times during the 100 simulations for Good project management level. For Moderate management, this figure was about 60%.

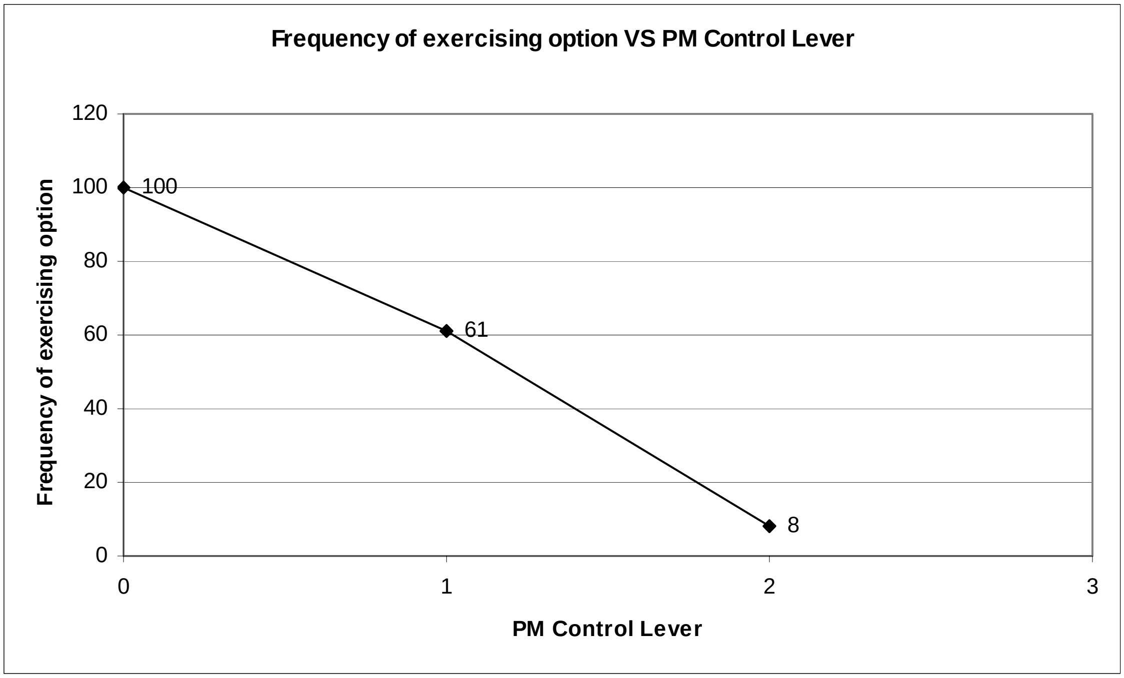

Fig. 21. Frequency of exercising option

Option Valuation Validation

Table 1 lists the behavior of option values for call and put options with increase in the variables used to calculate option values. The model is validated for these properties of real options. Table 9 (Based on Table 1, Pg 8) reflects the results obtained by modeling the base case as a call option.

Table 9. Model Validation of Option Value Characteristics

Increase in variable	Call Option Value	In the model base case
Underlying Asset Value	Increases	Increases
Exercise Price	Decreases	Decreases
Interest rate	Increases	Decreases
Time to expiration	Increases	Increases
Volatility	Increases	Increases

Covariance

The covariance is changed from 0 to 60% and its effects on option value are studied for each type of management.

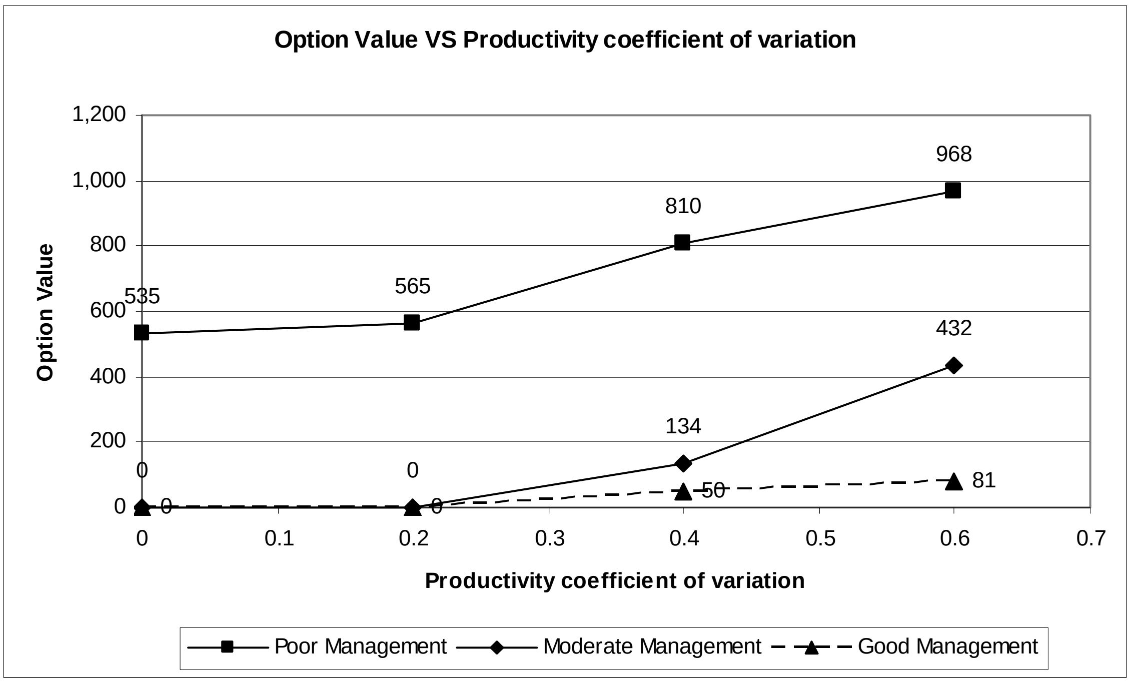

Fig. 22. Effect of covariance on option value

As the volatility (productivity coefficient of variation) increases, the option value for all three management policies increases as shown in Figure 22.

Unit cost

The unit cost of completing work (QA, IC and CH) is changed from 0 to 50 thousand dollars per work package. Its effect on option value is studied.

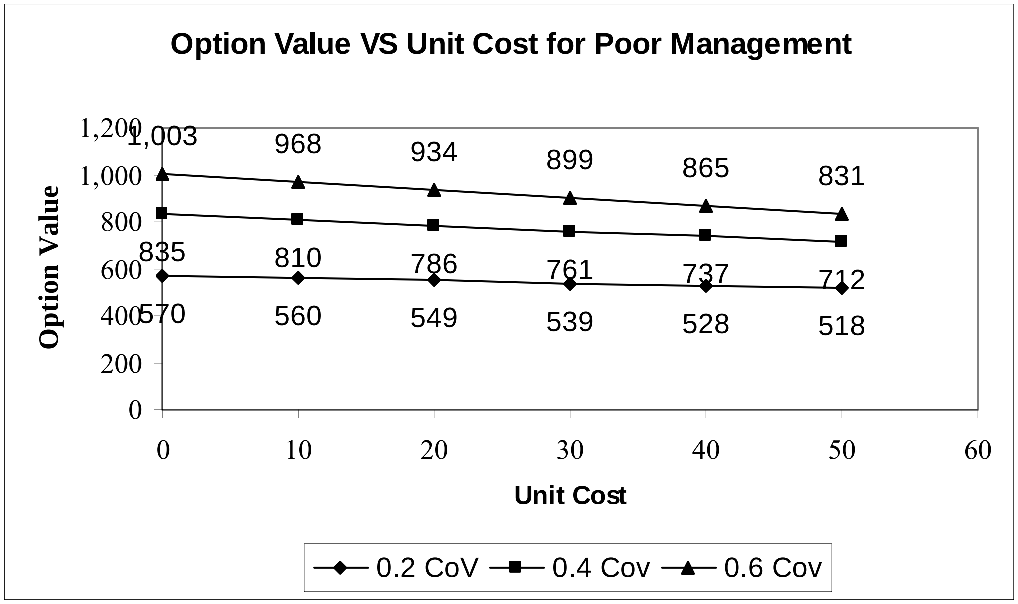

Fig. 23. Effect of unit cost on option value with Poor management

Figures 23, 24 and 25 show that as the unit cost increases, the option value for all three management policies increases. In order to validate the accuracy of the result, this is done for three values of covariance (20%, 40% and 60%).

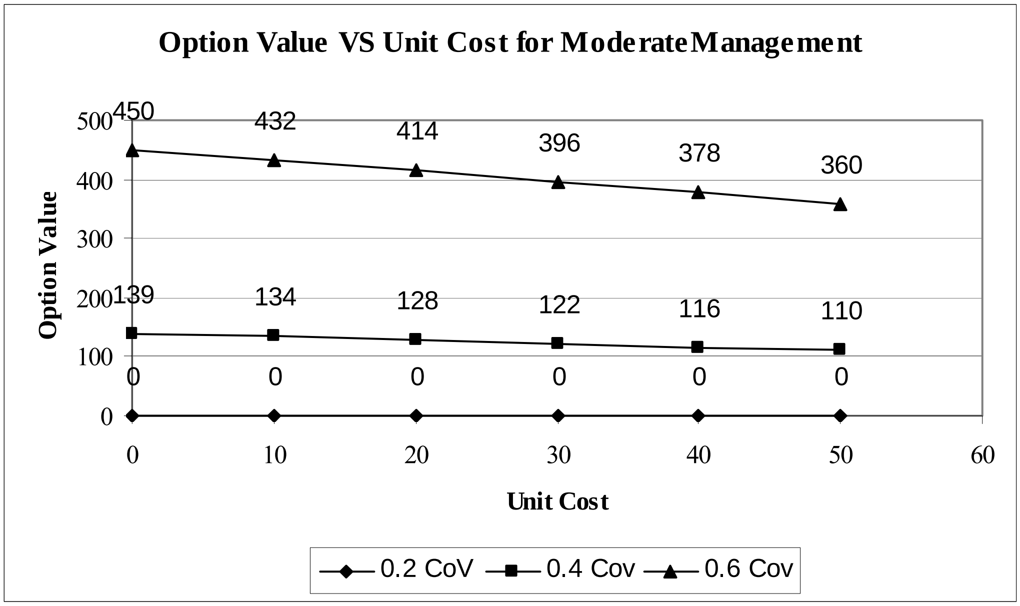

Fig. 24. Effect of unit cost on option value with Moderate management

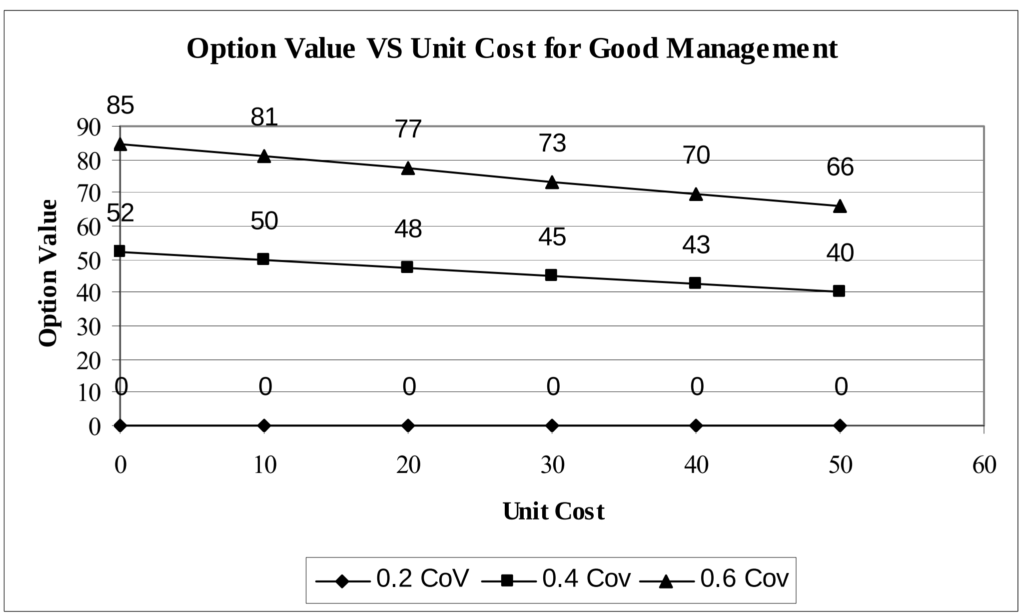

Fig. 25. Effect of unit cost on option value with Good management

Exercise Price

The exercise price is changed from 0 to 500 thousand dollars. Its effect on option value is studied.

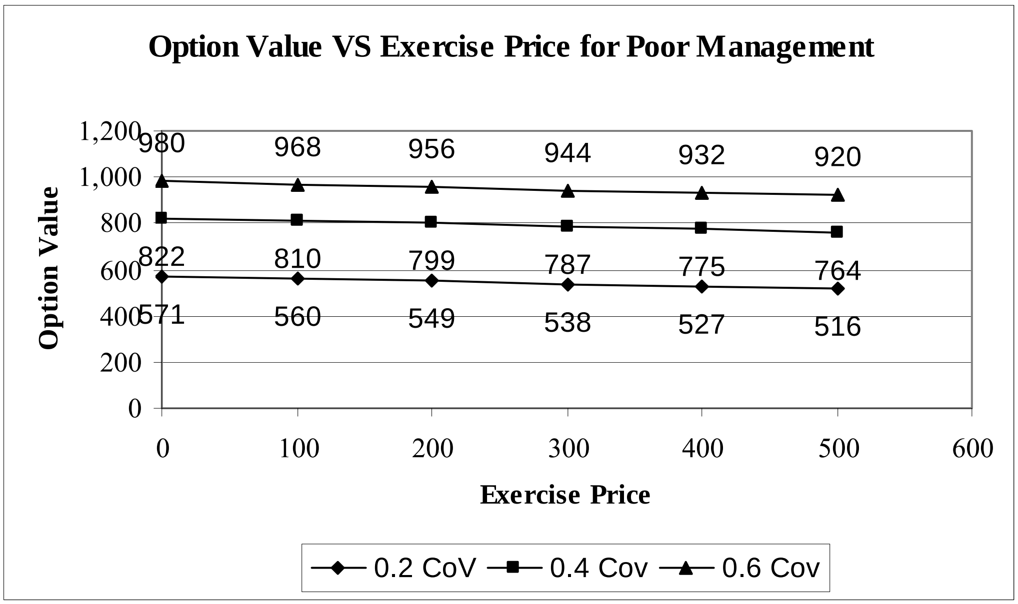

Fig. 26. Effect of exercise price on option value with Poor management

Figures 26, 27 and 28 show that as the exercise price increases, the option value for all three management policies increases. In order to validate the accuracy of the result, three values of covariance (20%, 40% and 60%) are considered.

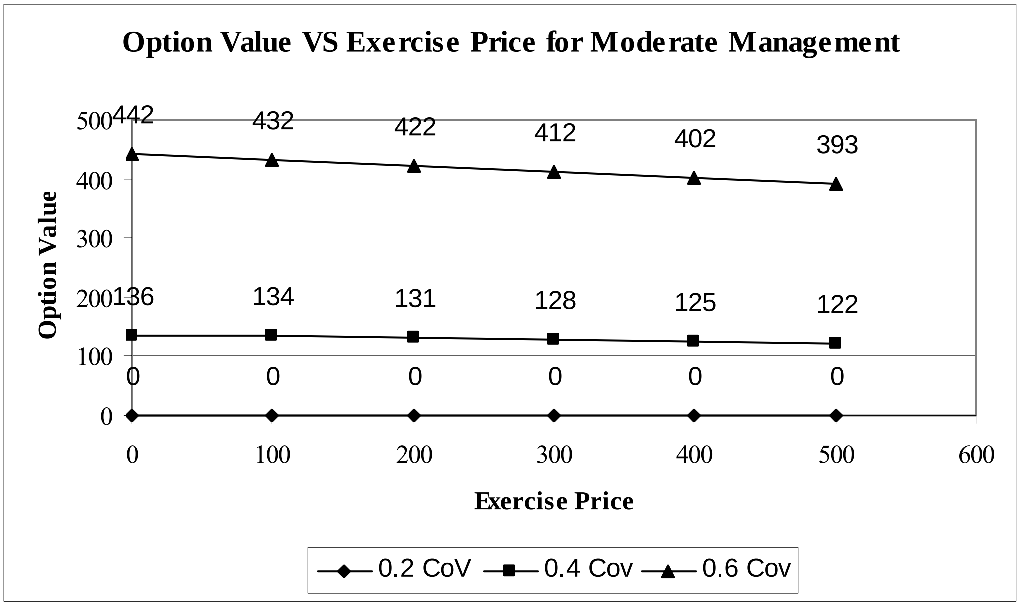

Fig. 27. Effect of exercise price on option value with Moderate management

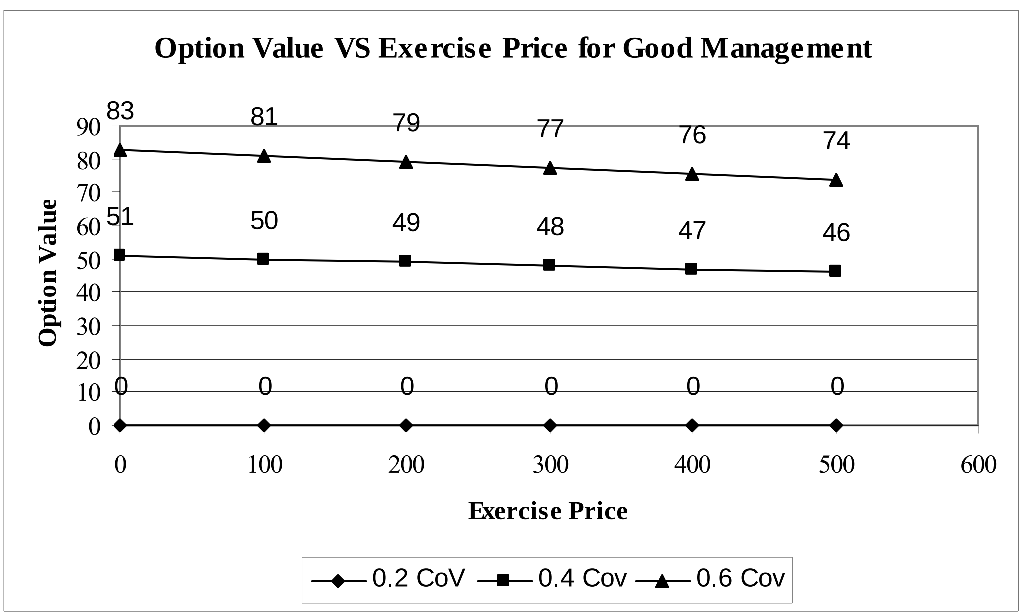

Fig. 28. Effect of exercise price on option value with Good management

Interest Rate

Figures 29, 30 and 31 show that as the annual discount rate increases, the option value for all three management policies decreases. In order to validate the accuracy of the result, three values of covariance (20%, 40% and 60%) are considered.

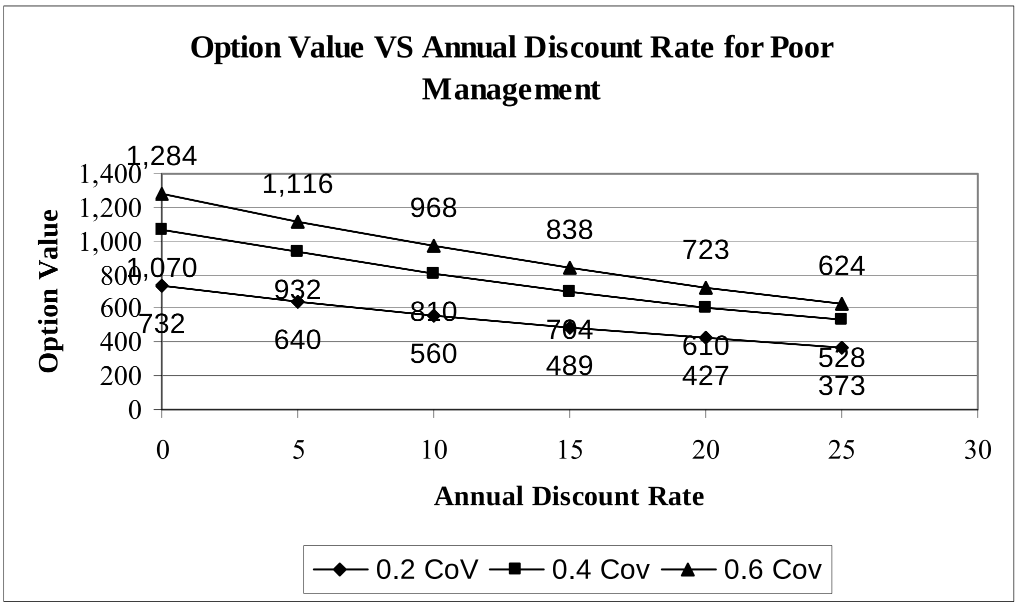

Fig. 29. Effect of discount rate on option value with Poor management

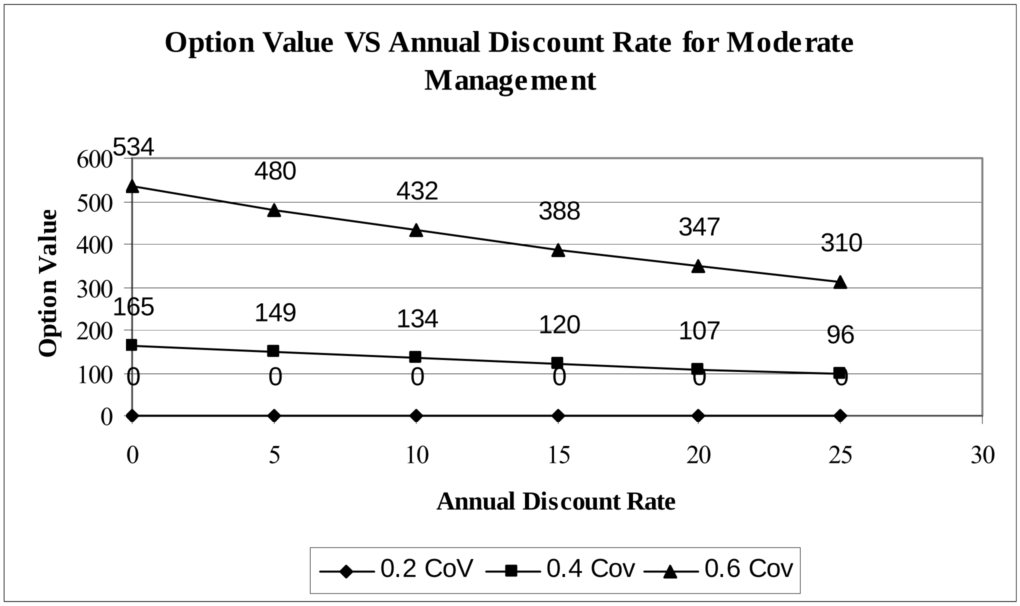

Fig. 30. Effect of discount rate on option value with Moderate management

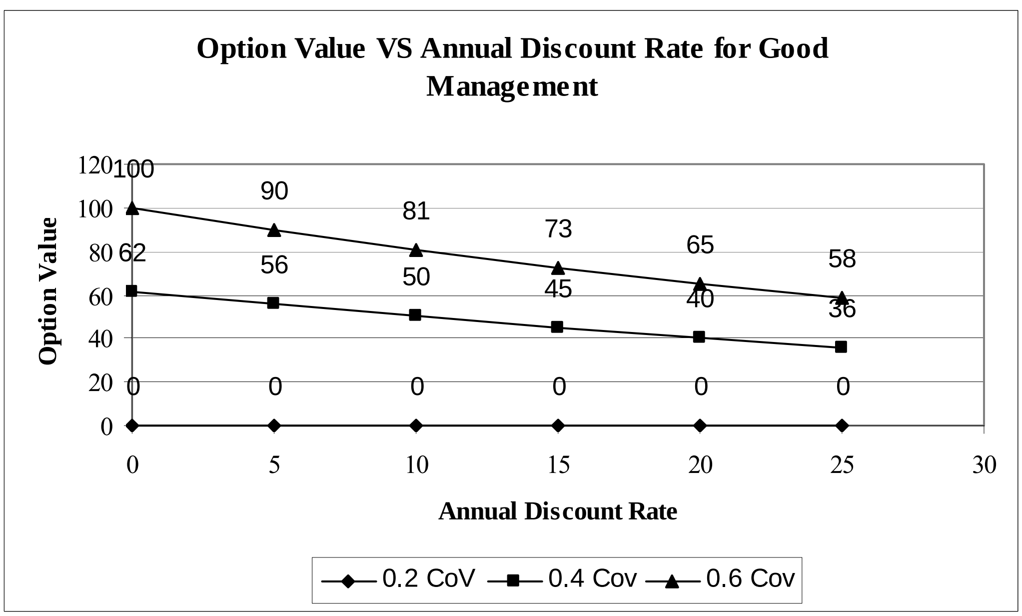

Fig. 31. Effect of discount rate on option value with Good management

Time to Expiration

Figures 32, 33 and 34 show that as the exercise date increases, the option value for all three management policies increases. In order to validate the accuracy of the result, this is performed for three values of covariance (20%, 40% and 60%), more so for higher values of covariance.

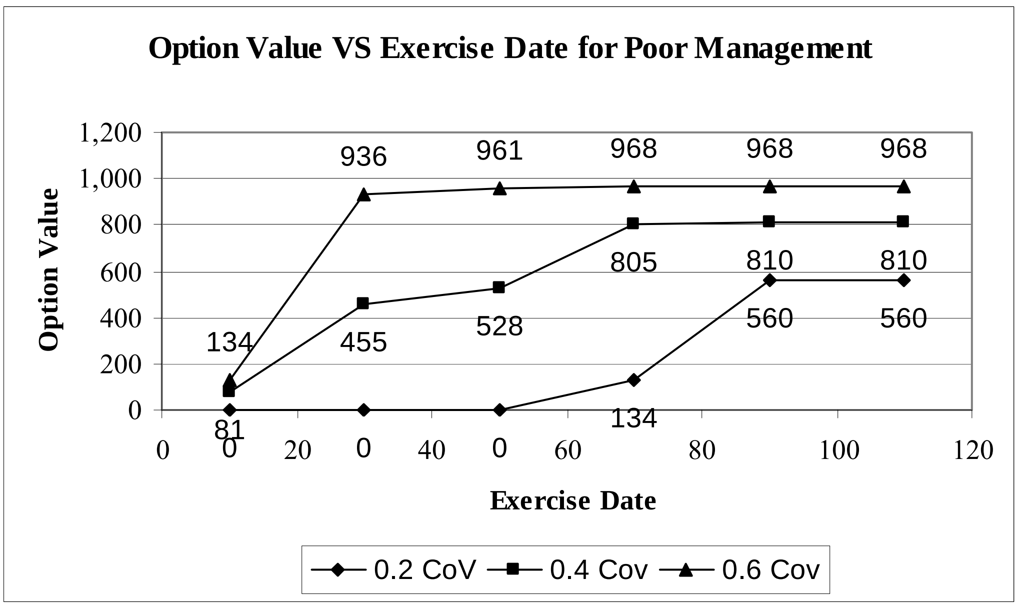

Fig. 32. Effect of exercise date on option value with Poor management

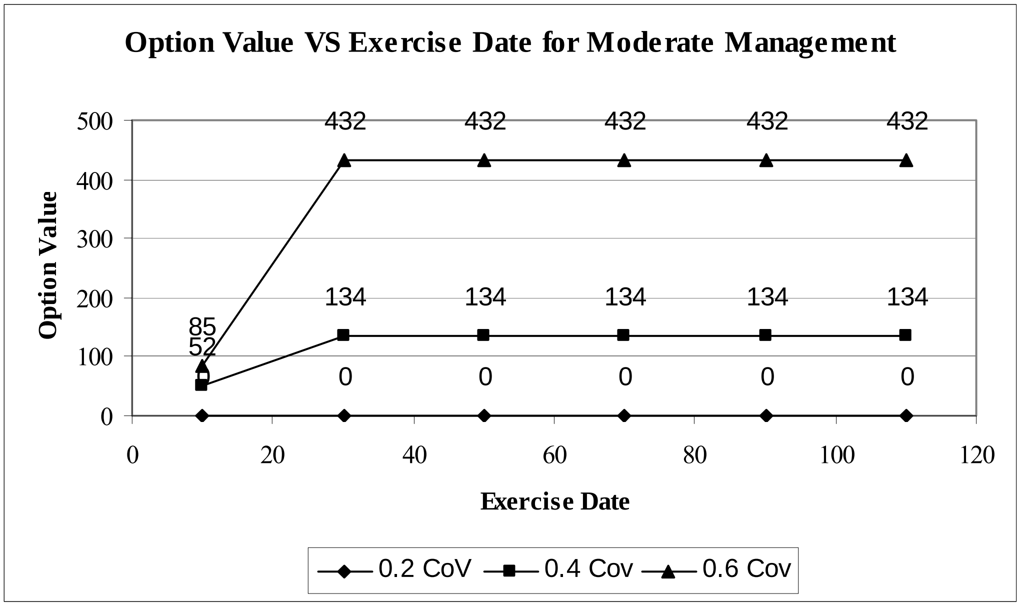

Fig. 33. Effect of exercise date on option value with Moderate management

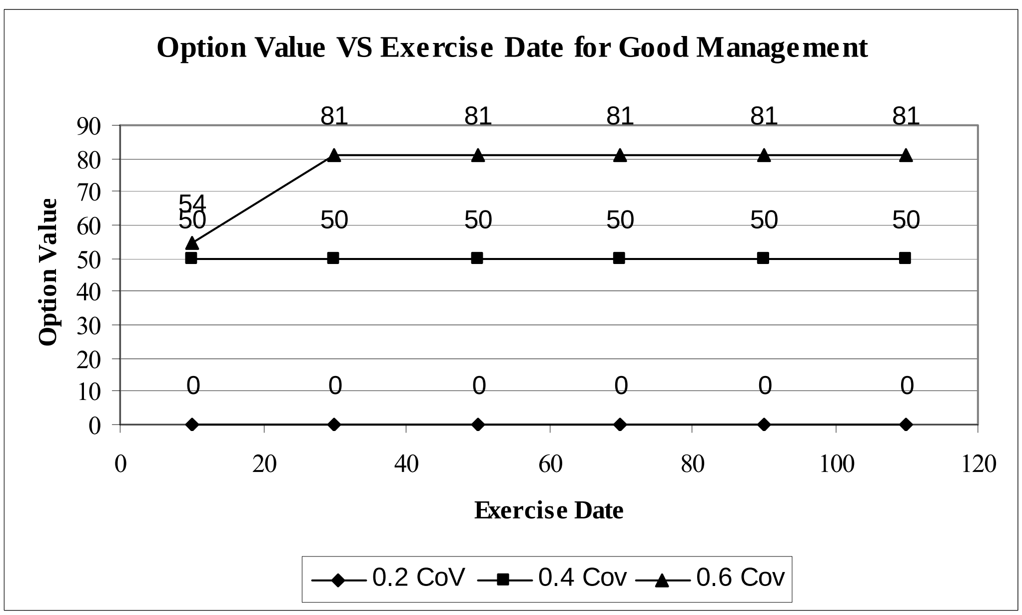

Fig. 34. Effect of exercise date on option value with Good management

The value of an option increases as the value of the underlying asset (stock price) increases, if the exercise price is held constant. When the value of the underlying asset becomes large, the option price approaches the value of the underlying asset less the present value of the exercise price. The value of an option increases with both the volatility and the time to expiration. This is because the probability of large stock price changes during the remaining life of an option and depends on the standard deviation and the number of periods until the option expires.

Thus the model satisfies all the characteristics of option values as given in Table 9 except for discount rate. This happens because the model discounts the present value of the accumulated project cost but does not discount the expected revenue with the changing discount rates. Thus, the model aptly reflects option valuation characteristics given in Table 9 and hence it is validated.

VII. RESULTS

After simulating the model as stated in research design, the following results were obtained.

Figure 35 shows that the variance for Average forecasted completion date reduces initially as project management level increases.

H1A: As project management increases, the variance of forecasted completion date decreases.

σS-G < σ S-M < σ S-P

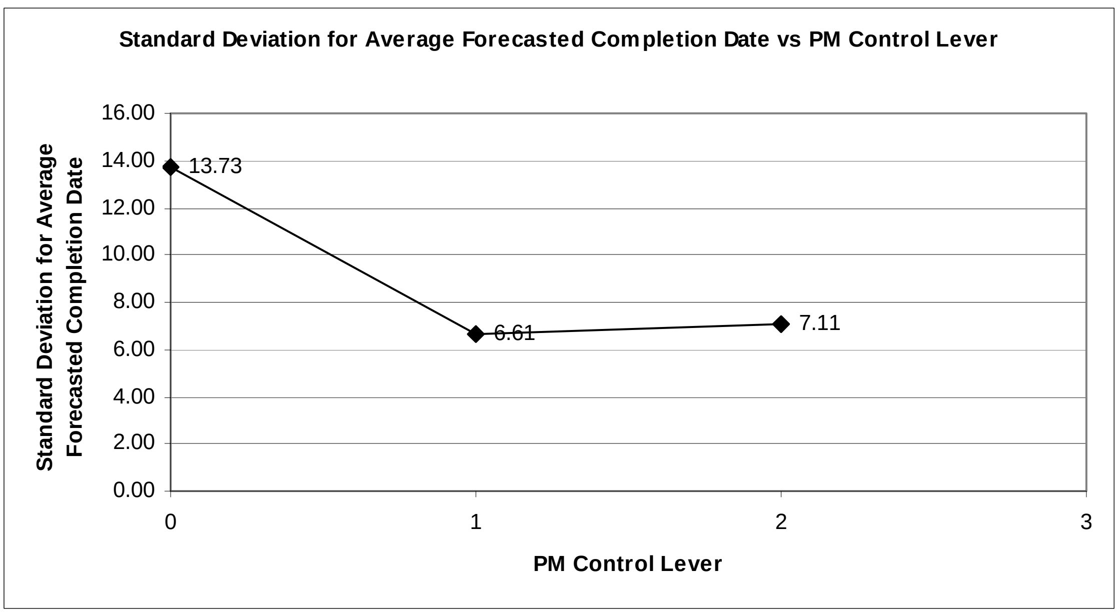

Fig. 35. Hypothesis H1A

As seen from Figure 35, the standard deviation for average forecasted completion date reduces as the resource management strategy improves from Poor to moderate. However this slope does not significantly continue from moderate to Good project management. Thus Figure 35 partially supports the hypothesis.

H2A: As project management increases, the mean forecasted lateness decreases.

$\mu L\text{-}G < \mu L\text{-}M < \mu L\text{-}P$

Figure 36 shows that as project management level increases, the mean forecasted lateness reduces.

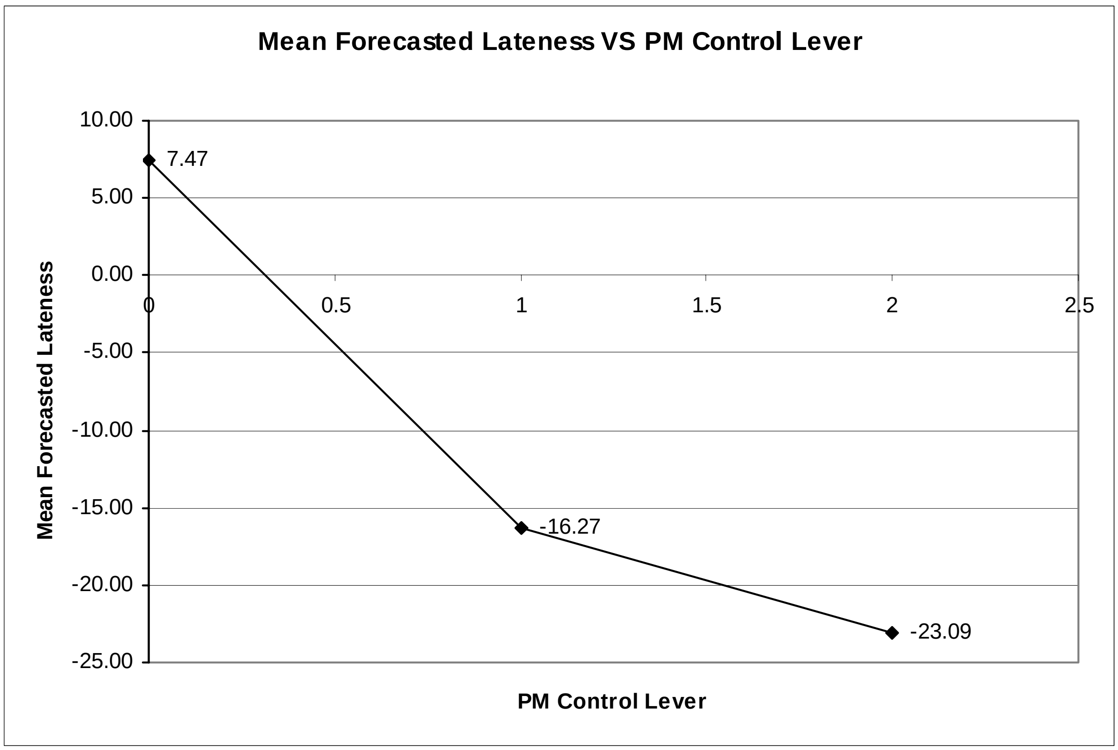

Fig. 36. Hypothesis H2A

As seen from Figure 36, the mean forecasted lateness of the project reduces as the project management gets better from Poor to Moderate and then to Good. Thus, Figure 36 supports the hypothesis that as project management increases, the mean forecasted lateness decreases.

H1B: As variance in the forecasted completion date decreases, the value of real options to reverse outsourcing decreases.

VP > VM > VG

Figure 37 shows that as the standard deviation of average forecasted completion date increases (variance in the forecasted completion date decreases), the value of real options (to reverse outsourcing) decreases from Poor management to Moderate and Good Management. However this does happen when project management level changes from Moderate to Good.

VP represents the value of the real option for Poor project management.

VM represents the value of the real option for Moderate project management.

VG represents the value of the real option for Good project management.

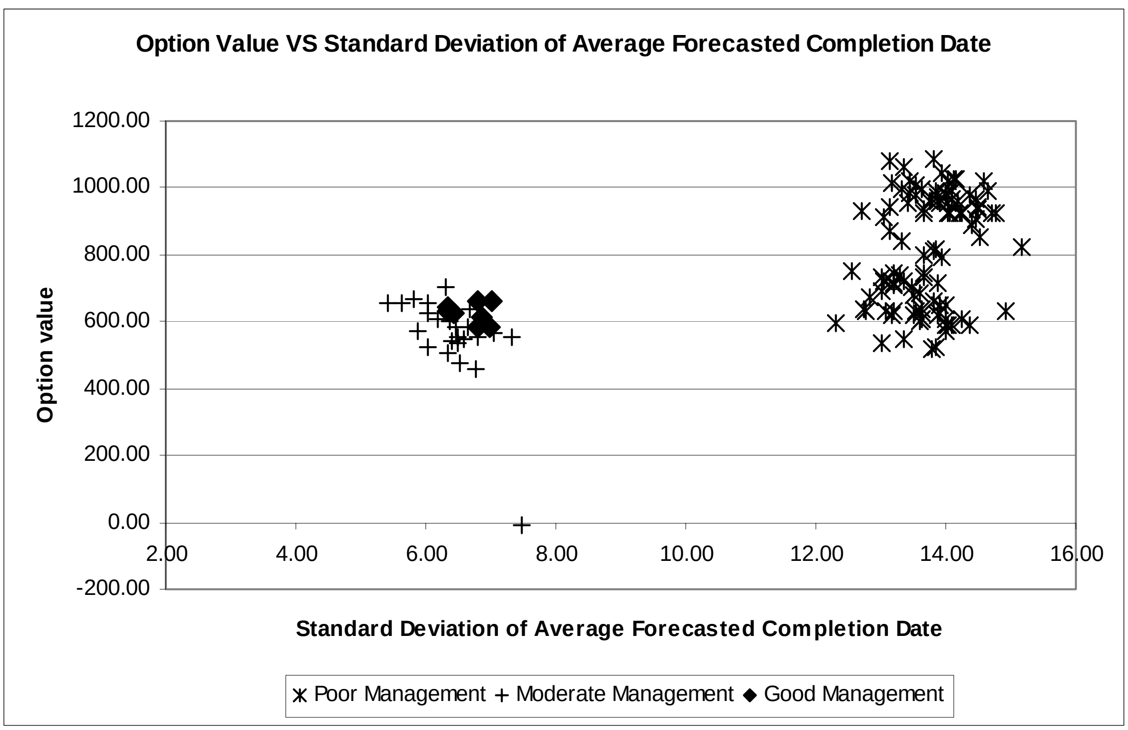

Fig. 37. Hypothesis H1B

The results are a little unclear here. This is because the slope of a line through the different management levels can be positive or neutral. But as seen from the above figure, there seems more support to the hypothesis than no support at all. Thus, Figure 37 partially supports the hypothesis.

H2B: As the mean forecasted lateness decreases, value of real options to reverse outsourcing decreases.

VP > VM > VG

Figure 38 shows that as the mean forecasted lateness decreases, the value of real options (to reverse outsourcing) for Moderate management decreases as compared to the value of real option s for Poor Management. However this does not happen when project management level changes from Moderate to Good.

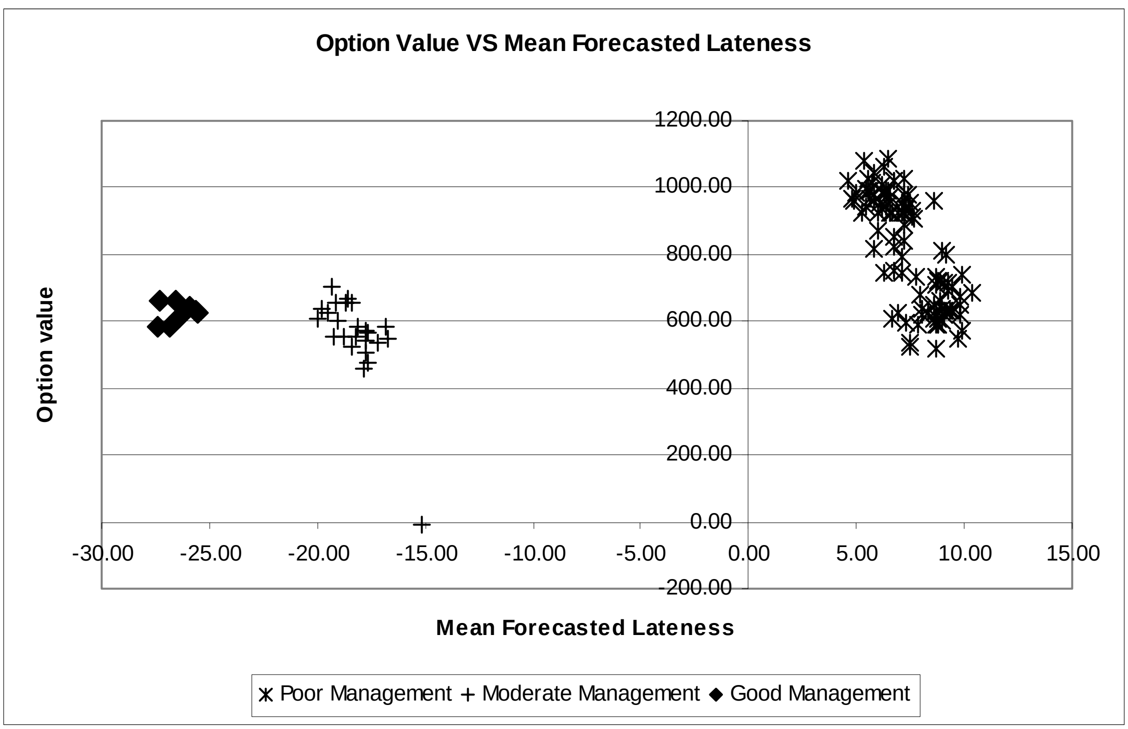

Fig. 38. Hypothesis H2B

The results are a little unclear here although the slope of a line through the different management levels appears to be positive. Hence as seen from the above figure, there seems more support to the hypothesis than no support at all. Thus, Figure 38 partially supports the hypothesis.

The general hypothesis is that as the level of project management increases, the value of the option to reverse outsourcing decreases.

As stated earlier, it is suspected that project management has an impact on option value. The following graph Figure 39 shows that as the level of project management increases, the option value significantly reduces. The option values have been calculated using Equation 25. The NPVs used for calculating option value of the project are an average value obtained by running 200 simulations.

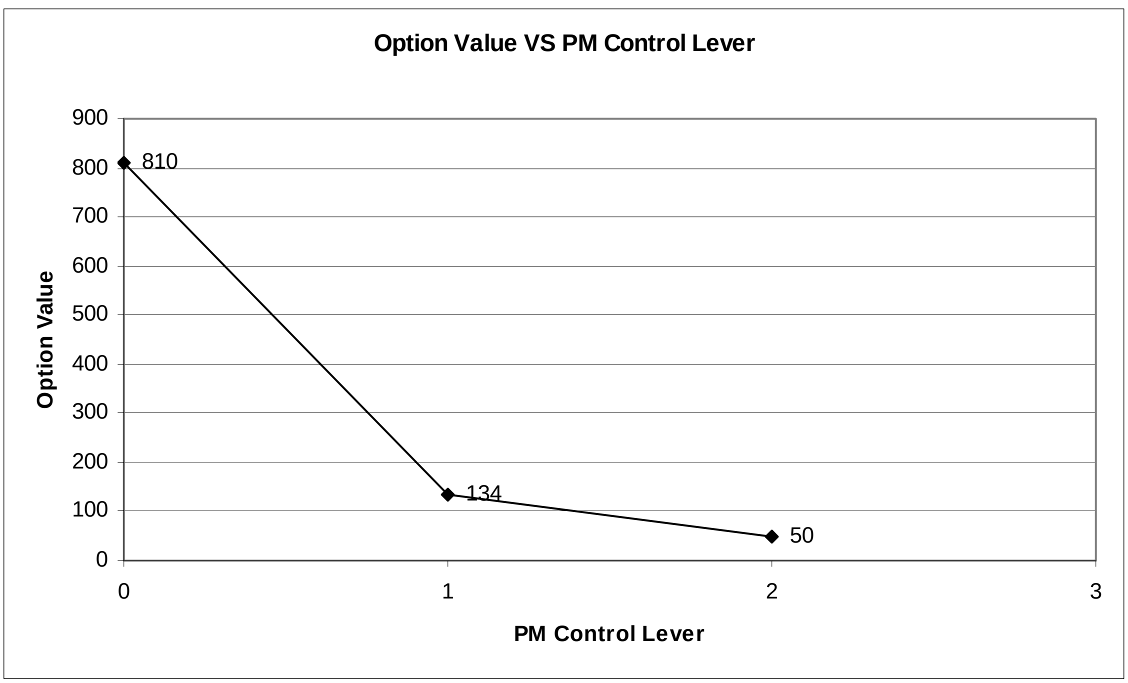

Fig. 39. General Hypothesis

As seen from Figure 39, the option value clearly decreases as the project management level increases from Poor to Moderate and then to Good. Thus Figure 39 supports the hypothesis.

VIII. CONCLUSIONS

The research question focused on how project management by the holder of real options impacted the value of options to improve performance. As seen from the results, it can be concluded that,

- Project management reduces the value of real options to a certain extent by reducing the variance of the exercise signal from the asset.
- Project management partially reduces the value of real options by reducing the difference between conditions for exercising the option and the mean exercise signal from the asset.

The project manager can thus manage uncertainty effectively, improving project performance by using a real options approach. The model has shown that project management has an effect on the value of the real option.

The research partially proves that better project management adds value to the project. In practice, the project manager can improve project performance by using flexible management strategies. The project manager can value flexibility by using the real options approach. While valuing the real options, the impact of the option holder on the performance of the project must be considered. The industry can use a more flexible approach to manage uncertainty effectively by considering options in a project.

Although this is preliminary research, it can be concluded that better project management, reduces the value of an option and leads to a better project performance. Thus, the ability of an option holder to impact the project must not be ignored. While using a real options approach in theory, this factor should be accounted for.

Future Work

This research can be used as a basis for further increasing the confidence in the premise that better project management reduces option value. In practice, there will be multiple sources of uncertainty. The model can be further developed to accommodate these sources of uncertainty. A thorough sensitivity analysis of the model will lead to identifying critical parameters that affect project performance and hence option value. This work was based on the assumption that the probability of rework is 40%. The model can be tested for a range of rework probabilities and levels of management. Another improved level of management could be added to the model and the effects studied, thus increasing the scope of the model. The model can also be used as a basic model and expanded for a variety of applications in project management. This research may also be applied to a real project and the effect of maintaining a flexible strategy may be studied using an expanded version of the model.

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APPENDIX

List of Equations

(001) Accumulated Project Cost= INTEG (Applied Weekly Project Cost, 0)

Units: Thousand Dollars

(002)Accumulated Project Cost Present Value= INTEG (Present Value of Weekly Costs, 0)

Units: Thousand Dollars

(003) Actual Exercise Date= INTEG (Add to Actual Exer Date, 0)

Units: Week

(004) Add to Actual Exer Date= (1-Exercise Trigger)

Units: Dmnl

(005) Add to Project duration= (IF THEN ELSE(Work Released<=Project Scope*"Scope Fraction indicating \"Finished\"" , 1, 0)

Units: Dmnl

(006) Adjust Max Avg Forecasted Compl Date= (Max(0,Average Forecasted Completion Date-Max Avg Forecasted Compl Date))

Units: Dmnl

(007) Annual Discount Rate= 10

Units: Percent/Year

(008) Applied Exercise Cost= (Unit Exercise Cost*(Pull Trigger*TIME STEP))

Units: Thousand Dollars/Week

Use of Pull Trigger (pulse) adds exercise cost to project only once at exercise date.

(009) Applied Resource Adjustment Time= 30

Units: Week

(010) Applied Weekly Project Cost= (IF THEN ELSE(Project Complete Flag=0, Weekly Project Cost, 0)

Units: Thousand Dollars/Week

(011) Average Forecasted Completion Date= INTEG (Change Average Forecasted Completion Date, Deadline)

Units: Week

(012) Avg Forecasted Compl Date for Std Dev= (IF THEN ELSE (Project Complete Flag=0, Average Forecasted Completion Date, 0))

Units: Week

(013) Change Average Forecasted Completion Date= (Forecasted Completion Date-Average Forecasted Completion Date)/"Managerial reluctance to exercise (Forecasted Completion Date Average Time)"

Units: Dmnl

(014) Change Backlog= INTEG (-Change rate+ Discover Internal Changes, 0)

Units: WP

(015) Change Change Resource Fraction= (Change Resource Fraction Target-Change Resource Quantity Fraction)/Resource adjustment time)

Units: 1/Week

(016) Change Completion Resource Fraction= ((Completion Resource Fraction Target-Completion Resource Quantity Fraction)/Resource adjustment time)

Units: 1/Week

(017) Change Process duration= 1

Units: Week

(018) Change Productivity= (Outsourcing Change Productivity*(1-Exercise Trigger))+("In-House Change Productivity" *Exercise Trigger)

Units: WP/(Week*Crew)

(019) Change Quality Assurance Resource Fraction= ((Quality Assurance Resource Fraction Target-Quality Assurance Resource Quantity Fraction)/Resource adjustment time)

Units: 1/Week

(020) Change rate= MIN(Change Backlog/Change Process duration, Change Resource Rate)

Units: WP/Week

(021) Change Resource Fraction Target= ZIDZ(Forecasted Change Resource Demand, Total Resource Demand)

Units: Dmnl

(022) Change Resource Quantity Fraction= INTEG (Change Change Resource Fraction, 0)

Units: Dmnl

(023) Change Resource Rate= (Total Resource Quantity*Change Resource Quantity Fraction*Common Res Productivity)

Units: WP/Week

(024) Change time required= ZIDZ(Change Backlog,Max(0.75,Change rate))

Units: Week

(025) Common mean Outsourced Res Prod= ((Outsourcing Change Productivity+ Outsourcing Initial Completion Productivity +Outsourcing QA Productivity)/3)

Units: WP/(Week*Crew)

(026) Common mean Res Prod=((Mean Ch Res Prod+Mean IC Res Prod+Mean QA Res Prod)/3)

Units: WP/(Week*Crew)

(027) Common Res Productivity= RANDOM NORMAL(Min Res Prod, Max Res Prod, Common mean Res Prod, Prod Coeff of Variation *Common mean Res Prod, NOISE SEED)

Units: WP/(Week*Crew)

(028) Completion process duration= 1

Units: Week

(029) Completion Resource Fraction Target= ZIDZ(Forecasted Completion Resource demand,Total Resource Demand)

Units: Dmnl

(030) Completion Resource Quantity Fraction= INTEG (Change Completion Resource Fraction, 1)

Units: Dmnl

(031) Completion Resource Rate= (Total Resource Quantity*Completion Resource Quantity Fraction*Common Res Productivity)

Units: WP/Week

(032) Concurrence effect= 2

Units: Dmnl

(033) Cost of Initial Completion= Initial Completion rate*Unit Cost of Initial Completion

Units: Thousand Dollars/Week

(034) Cost of Quality Assurance= Quality Assurance rate*Unit Cost of Quality Assurance

Units: Thousand Dollars/Week

(035) Cost of Rework= Change rate*Unit Cost of Rework

Units: Thousand Dollars/Week

(036) Deadline= 89

Units: Week

Use mean of maximum forecasted completion dates for no-option for each rework probability for Moderate project management.

(037) Discover Internal Changes= Quality Assurance rate*Iteration Fraction

Units: WP/Week

(038) Elapsed Time for Forecasting Completion= (IF THEN ELSE(Project Complete Flag=0, Time, Project Duration))

Units: Week

(039) Exercise Trigger= INTEG (Pull Trigger, 0)

Units: Dmnl

(040) FINAL TIME = 150

Units: Week

The final time for the simulation

(041) Forecasted Change Resource Demand= (ZIDZ(((No Resource Management Switch*No Change Work Required)+(Myopic Resource Management Switch *Myopic Change Work Required)+(Short

Foresighted Resource Management Switch*Short Foresight Change Work Required)+(Long Foresight Resource Management Switch*Long Foresight Change Work Required)), (Mean Ch Res Prod*Max(Time Available to Forecasted Completion Date, Time Available to Deadline))))

Units: Crew

(042) Forecasted Completion Date= Elapsed Time for Forecasting Completion+ Time Required

Units: Week

(043) Forecasted Completion Resource demand= (ZIDZ(((No Resource Management Switch*No Completion Work Required)+(Myopic Resource Management Switch *Myopic Completion Work Required)+(Short Foresighted Resource Management Switch *Short Foresight Completion Work Required)+(Long Foresight Resource Management Switch *Long Foresight Completion Work Required)), (Mean IC Res Prod*Max(Time Available to Forecasted Completion Date,Time Available to Deadline))))

Units: Crew

(044) Forecasted QA Resource demand= (ZIDZ (((No Resource Management Switch*No QA Work Required)+(Myopic Resource Management Switch *Myopic QA Work Required)+(Short Foresighted Resource Management Switch*Short Foresight QA Work Required)+(Long Foresight Resource Management Switch*Long Foresight QA Work Required)), (Mean QA Res Prod*Max(Time Available to Forecasted Completion Date ,Time Available to Deadline))))

Units: Crew

(045) IC time required= (ZIDZ (Initial Completion Backlog/Iteration Fraction, Max(0.75,Initial Completion rate)))

Units: Week

(046) "In-House Change Productivity"= (Outsourcing Change Productivity*Productivity Improvement Factor)

Units: WP/(Week*Crew)

(047) "In-House Initial Completion Productivity"= (Outsourcing Initial Completion Productivity*Productivity Improvement Factor)

Units: WP/(Week*Crew)

(048) "In-House QA Productivity"= (Outsourcing QA Productivity*Productivity Improvement Factor)

Units: WP/(Week*Crew)

(049) Initial Completion Backlog= INTEG (-Initial Completion rate,Project Scope)

Units: WP

(050) Initial Completion Productivity= (Outsourcing Initial Completion Productivity*(1-Exercise Trigger))+("In-House Initial Completion Productivity"*Exercise Trigger)

Units: WP/(Week*Crew)

(051) Initial Completion rate= MIN(Completion Resource Rate,Initial Completion Backlog/Completion process duration)

Units: WP/Week

(052) INITIAL TIME = 0

Units: Week

The initial time for the simulation

(053) Iteration Fraction= 0.4

Units: Dmnl

Probability of a Change being needed * Probability of a Needed Change being discovered

(054) Long Foresight Change Work Required= (Change Backlog+(Quality Assurance Backlog*Iteration Fraction)+(Iteration Fraction*(Initial Completion Backlog+ Change Backlog)))

Units: WP

(055) Long Foresight Completion Work Required=Initial Completion Backlog

Units: WP

(056) Long Foresight QA Work Required= (Quality Assurance Backlog+(Change Backlog+Initial Completion Backlog)+(Iteration Fraction *Quality Assurance Backlog+ Change Backlog))

Units: WP

(057) Long Foresight Resource Management Switch= (IF THEN ELSE(PM control lever=3, 1, 0))

Units: Dmnl

(058) "Managerial reluctance to exercise (Forecasted Completion Date Average Time)" =3

Units: Week

(059) Max Avg Forecasted Compl Date= INTEG (Adjust Max Avg Forecasted Compl Date, Average Forecasted Completion Date)

Units: Week

(060) Max Exercise Date= 150

Units: Week

(061) Max Res Prod= 2*Common mean Res Prod

Units: WP/(Week*Crew)

Set so that max variance is equal on both sides of mean to prevent bias for high productivity with high coefficient of variance.

(062) Mean Ch Res Prod= Change Productivity

Units: WP/(Week*Crew)

(063) Mean IC Res Prod= Initial Completion Productivity

Units: WP/(Week*Crew)

(064) Mean QA Res Prod= Quality Assurance Productivity

Units: WP/(Week*Crew)

(065) Min Res Prod= 0

Units: WP/(Week*Crew)

(066) Myopic Change Work Required= Change Backlog

Units: WP

(067) Myopic Completion Work Required= Initial Completion Backlog

Units: WP

(068) Myopic QA Work Required= Quality Assurance Backlog

Units: WP

(069) Myopic Resource Management Switch= (IF THEN ELSE(PM control lever=1, 1, 0))

Units: Dmnl

(070) NPV of Project= Present Value of Income-Accumulated Project Cost Present Value

Units: Thousand Dollars

(071) No Change Work Required= Project Scope/3

Units: WP

(072) No Completion Work Required= Project Scope/3

Units: WP

(073) No QA Work Required= Project Scope/3

Units: WP

(074) No Resource Management Switch= (IF THEN ELSE(PM control lever=0, 1, 0))

Units: Dmnl

(075) NOISE SEED= 5

Units: Dmnl

(076) Option Availability Flag= (IF THEN ELSE(Option Switch=1:AND:Time<=Max Exercise Date, 1, 0))

Units: Dmnl

(077) Option Switch= 1

Units: Dmnl

(078) Outsourcing Change Productivity= 1

Units: WP/(Week*Crew)

(079) Outsourcing Initial Completion Productivity= 1

Units: WP/(Week*Crew)

(080) Outsourcing QA Productivity= 1

Units: WP/(Week*Crew)

(081) Percent= 100

Units: Percent

(082) PM control lever= 1

Units: Dmnl

(083) Present Value Fraction= (EXP(-(Weekly Discount Rate*Time)))

Units: Dmnl

(084) Present Value of Income= 25000

Units: Thousand Dollars

(085) Present Value of Weekly Costs= (IF THEN ELSE(Project Complete Flag=0, Weekly Project Cost Present Value, 0))

Units: Thousand Dollars/Week

(086) Prod Coeff of Variation= 0.4

Units: Dmnl

(087) Productivity Improvement Factor= 1.1

Units: Dmnl

(088) Project Complete Flag= (IF THEN ELSE(Work Released<=Project Scope*"Scope Fraction indicating \"Finished\"", 0, 1))

Units: Dmnl

(089) Project Duration= INTEG (Add to Project duration, 0)

Units: Week

(090) Project Scope= 200

Units: WP

(091) Pull Trigger= (Option Availability Flag*IF THEN ELSE(Average Forecasted Completion Date> Deadline: AND: Exercise Trigger=0, 1/TIME STEP, 0)

Units: 1/Week

(092) QA Process Duration = 1

Units: Week

(093) QA Resource Rate= (Total Resource Quantity*Quality Assurance Resource Quantity Fraction*Common Res Productivity)

Units: WP/Week

(094) QA time required= ZIDZ(Quality Assurance Backlog,Max(0.75,Quality Assurance rate))

Units: Week

(095) Quality Assurance Backlog= INTEG (Initial Completion rate-Discover Internal Changes -Release Work+ Change rate, 0)

Units: WP

(096) Quality Assurance Productivity= (Outsourcing QA Productivity*(1-Exercise Trigger))+("In-House QA Productivity" *Exercise Trigger)

Units: WP/(Week*Crew)

(097) Quality Assurance rate=MIN(Quality Assurance Backlog/QA Process Duration,QA Resource Rate)

Units: WP/Week

(098) Quality Assurance Resource Fraction Target= ZIDZ(Forecasted QA Resource demand,Total Resource Demand)

Units: Dmnl

(099) Quality Assurance Resource Quantity Fraction= INTEG (Change Quality Assurance Resource Fraction,0)

Units: Dmnl

(100) Release Work=Quality Assurance rate-Discover Internal Changes

Units: WP/Week

(101) Resource adjustment time= (0*TIME STEP)+(1*Applied Resource Adjustment Time)

Units: Week

(102) SAVEPER = TIME STEP

Units: Week

The frequency with which output is stored

(103) "Scope Fraction indicating \"Finished\""= 0.995

Units: Dmnl

(104) Sequential time required= IC time required+ QA time required+ Change time required

Units: Week

(105) Short Foresight Change Work Required= Change Backlog+(Quality Assurance Backlog*Iteration Fraction)

Units: WP

(106) Short Foresight Completion Work Required= Initial Completion Backlog

Units: WP

(107) Short Foresight QA Work Required= Quality Assurance Backlog+(Initial Completion Backlog+ Change Backlog)

Units: WP

(108) Short Foresighted Resource Management Switch= (IF THEN ELSE(PM control lever=2, 1, 0))

Units: Dmnl

(109) Time Available to Deadline= Max(0,Deadline-Time)

Units: Week

(110) Time Available to Forecasted Completion Date= (Forecasted Completion Date-Time)

Units: Week

(111) Time Required= ((1-Project Complete Flag)*(Sequential time required)/Concurrence effect)

Units: Week

(112) TIME STEP = 0.125

Units: Week

(113) Total Resource Demand= (Forecasted Change Resource Demand+ Forecasted Completion Resource demand+ Forecasted QA Resource demand)

Units: Crew

(114) Total Resource Quantity= 10

Units: Crew

(115) Unit Cost= 10

Units: Thousand Dollars/WP

(116) Unit Cost of Initial Completion= Unit Cost

Units: Thousand Dollars/WP

(117) Unit Cost of Quality Assurance= Unit Cost

Units: Thousand Dollars/WP

(118) Unit Cost of Rework= Unit Cost

Units: Thousand Dollars/WP

(119) Unit Exercise Cost= 100

Units: Thousand Dollars/Week

(120) Unit OH Cost= 150

Units: Thousand Dollars/Week

(121) Weekly Cost of Overhead= (IF THEN ELSE(Project Complete Flag=0, Unit OH Cost, 0))

Units: Thousand Dollars/Week

(122) Weekly Discount Rate= Annual Discount Rate/(Weeks per Year*Percent)

Units: 1/Week

(123) Weekly Project Cost= (Cost of Initial Completion+ Cost of Quality Assurance+ Cost of Rework+ Weekly Cost of Overhead +Applied Exercise Cost)

Units: Thousand Dollars/Week

(124) Weekly Project Cost Present Value= Present Value Fraction*Applied Weekly Project Cost

Units: Thousand Dollars/Week

(125) Weeks per Year= 52

Units: Week/Year

(126) Work Released= INTEG (Release Work, 0)

Units: WP

Taxonomy of Real Options

The following table describes the range of applications of real options:

Option	Description	Type of Flexibility	Guide to Literature
Deferral	Similar to an American Call option. Exists when management can defer the decision about the investment for a certain period of time. They are important in natural resource extraction industries, real estate development, farming and others.	Upside Potential	McDonald and Siegel (1986); Paddock, Siegel and Smith (1988); Tourinho (1979); Titman (1985); Ingersoll and Ross (1992); Dixit (1992)
Timing or Staging	Relates to the possibility of staging investments as a series of outlays to create both growth and abandonment options. Each stage can be viewed as an option on the value of subsequent stages (compound option). They are important in R&D intensive industries, capital-intensive projects and start-up ventures.	Upside Potential and Downside Protection	Brennan and Schwartz (1985); Majd and Pindyck (1987); Carr (1988); Trigeorgis (1993)
Altering Operating State	If market conditions are better than expected, a company may decide to increase its output level by investing in scaling-up the production plant either temporarily or permanently. Equally, if market conditions are adverse the firm might decide to temporarily shutdown production. Both cases are similar to call options. Important in natural resources industries where prices of output may vary constantly, commercial real estate, and in other cyclical industries such as fashion apparel and consumer goods	Upside Potential and Downside Protection	Brennan and Schwartz (1985); McDonald and Siegel (1985); Trigeorgis and Mason (1987); Pindyck (1988)
Growth	A growth option is similar to a European or American call. They exist when early investments in R&D, undeveloped land or reserves of a natural resource, information, create the opportunity of generating further revenues (I.e., developing a product and selling it in the market, exploiting the acquired reserves, and others). Growth opportunities are compound options, whose value depends on a pre-existing option.	Upside Potential	Myers (1977); Brealey and Myers (1991); Kester (1984, 1993); Trigeorgis (1988); Pindyck (1988); Chung and Charoenwong (1991)
Abandon ment	Similar to an American Put. If market conditions deteriorate, management can abandon current operations permanently and recoup the salvage value of the asset. It is important in capital-intensive industries with second-hand markets for their assets, such as the airline industry, railroads and financial services.	Downside Protection	Myers and Majd (1990), Sachdeva and Vanderberg (1993)
Switching	A combination of calls and puts that allow its owner to switch between two or more modes of operation, inputs or outputs. These options can create both product flexibility and process flexibility. They are important in facilities that are highly dependent on an input whose price varies constantly (E.g., oil, or any other commodity), and consumer electronics, toys, and autos industries where product specifications are subject to volatile demand.	Upside Potential and Downside Protection	Magrabe (1978); Kensinger (1987); Kulatilaka and Trigeorgis (1993)

Aadapted from Trigeorgis, ed., 1995, pp. 4-5

VITA

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