Executing Major Projects through Contractors

by

Nicholas A. McKenna

BE. Civil Engineering
University of Western Australia, 1993

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Signature of Author________________________
Nicholas A. McKenna
System Design & Management Program

Certified by___________________________
Nelson Repenning
Thesis Supervisor
Associate Professor

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Abstract

Project based organizational structures are utilized in many industries. The firms engaged in these significant endeavors, project sponsor and contractor alike, risk both capital and reputation in the market-place with each new project. Delivering projects effectively provides all the firms involved with desirable financial outcomes and market advantage. This thesis sets out to identify and understand the mechanisms established by the contracting structure that in part determine the outcome of the project. It is suggested that the nature of the relationship between project sponsor and contractor shapes the outcome of the project to a significant extent. Complex and challenging projects are made more so by the adversarial relationships that frequently exist between the sponsor and contractor(s). This thesis unpacks the underlying mechanisms that determine that relationship and begins to establish a theory of the project organization that could lead to improved project execution performance.

Thesis Supervisor: Professor Nelson Repenning

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Throughout my life they have been an inspiration to me. The example of their lives encouraged me to believe that I could accept any challenge, and that with hard work and dedication I could achieve my dreams.

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1.0 Introduction

Project based organizational structures are utilized in many industries and exist on many scales. At one end of the spectrum a "project team" may simply be a few individuals within a firm assigned to solve a specific problem. At the other extreme a project can involve thousand of individuals, employed by dozens of firms, spread across the globe, acting together to deliver a particular outcome over the course of several years. Examples of the second type of project are to be found in industries such as aerospace/defense (for weapons system development, satellites, etc) and the energy sector for infrastructure development (oil and gas pipelines, platforms, etc). These projects are often described as Large Engineering Projects or LEPs.

One element that tends to characterize LEPs is their use of contractual relationships to effect execution. While many small projects are executed by teams that exist within a single firm, LEPs typically involve a number of firms being brought together by the project sponsor to execute the project. At a minimum, there exists a separation between the project sponsor and the contractor(s) selected to execute the project. This structure is becoming more prevalent outside of the LEP sector as firms in a wide variety of industries turn to "outsourcing" arrangements.

The management and delivery of LEPs in an effective manner, i.e. on schedule and budget, is an extremely challenging endeavor. Failure to meet expectations tends to be the rule rather than the exception (Miller and Lessard 2000). A great deal of effort, and research, has been invested in trying to understand how these systems work, with a view to delivering better performance.

The core notion of this thesis is that formal contract relationships between sponsors and contractors is a significant determinant of major project outcomes. The initial perceived allocation of "rent" between participants in the endeavor shapes the ultimate performance of the project. This notion is built upon the following premises:

1. Many systems being developed through major project structures (utilizing contractors) are essentially integral systems (as compared to modular architectures).
2. Integral systems require significant investment in integration activities (communication, sharing of information, meetings, work sessions etc) in order to be successfully developed.
3. Motivation for investing in integration activities is developed through relationships between agents (firms, individuals) based on trust, mutual goals and relational contracts (Baker, Gibbons and Murphy 2002).
4. The firms engaged in a project organization will act to create value (as they perceive it) for their shareholders.

These four premises when taken together can lead to unexpected outcomes. The need, and desire, to optimize rent allocation can lead to the use of formal contract mechanisms which damage trust based relationship and undermine the investment in integration activities. This leads to sub-optimal project execution of complex integral systems. This thesis builds a formal model that highlights the mechanisms described above.

1.1 Motivation

The search for the hydrocarbons that fuel the world's economy is taking place in ever more challenging locations. Delivering oil and gas from the deepwater frontiers of the Gulf of Mexico, West Africa and South America requires the use of sophisticated technology and the deployment of significant economic and physical resources. The global energy companies turn to engineering and service firms to provide the technology, skills and assets, both human and material, required for delivering these major projects. The integrated energy companies – owners and operators of the infrastructure – assemble the project organization by, typically, competitively bidding and awarding contracts to the engineering service providers (contractors).

Many of these projects are characterized by their enormous scale, complexity and high level of novelty from a technology standpoint. Recovering hydrocarbons from reserves found several miles beneath the ocean floor while drilling and managing the production process from a platform located in thousands of feet of water, often hundreds of miles from land, requires engineers to push the boundaries of technology. In an environment of high technological risk and organizational complexity, delivering these major projects on schedule and within budget is extremely challenging. The firms engaged in these significant endeavors, project sponsor and contractor alike, put at risk both capital and reputation in the market-place with each project undertaken. Delivering these projects effectively would provide all the firms involved with desirable financial outcomes and market advantage relative to their competitors.

This thesis sets out to identify and understand the mechanisms established by the contracting structure that in part determine the outcome of the project. It is suggested that the nature of the relationship between project sponsor and contractor, founded as it is on a process of competitive bid and contract award, shapes the outcome of the project to a significant extent. Complex and challenging projects are made more so by the adversarial relationships that frequently exist between the sponsor and contractor(s). This thesis unpacks the underlying mechanisms that determine that relationship with a view to delivering improved project execution performance.

1.2 Thesis Organization and Objectives

Understanding the drivers of project performance in the oil and gas sector requires at a minimum the following. First, some level of familiarity with the business environment in which the projects take place and second, an appreciation of the technological complexity underlying these projects. Chapter two provides an introduction to both the business environment and the technology constraints within which the projects are embedded. An overview of the industry's recent performance in executing these projects is also presented. Chapter three reviews literature relevant to the problems under investigation and places this thesis in the context of that literature. Formal models of project and product development efforts exist within system dynamics and this rich heritage is explored. The literatures of contract theory, organizational behavior and product development are introduced to provide the broad framework within which this thesis resides.

Chapter four presents the key propositions that form this thesis: First, that the generation of errors or “re-work” in complex systems projects is a function of the effort directed towards integration activities. Second, that the investments firms and individuals make in integration activities is a function of the strength of the relationship between the project sponsor and contractor. Third, that the terms of the formal contract as determined *a-priori* by the participants, shape the relationship between contractor and sponsor. Chapter five presents a simple case study of a program of projects recently executed by an oil major. In chapter six a formal model of a project is developed. This model explicitly captures the sponsor-contractor relationship and its effects on project execution. Chapter seven presents the results and analysis of this model. Finally, in chapter eight the following conclusion is forwarded: that project sponsors need to award contracts that allow the contractors to succeed. Approaching contract pricing and negotiation as a zero-sum game is shown to result in higher than anticipated project costs under a wide rage of conditions and that to deliver cost effective projects, contractors should be fairly rewarded for their contribution. Finally, future avenues of research are suggested.

1.3 Approach and Methodology

The research in this thesis adopts the methodology of a case study and adds formal model building. A case study of a recent program[1] of major projects undertaken by an integrated energy company is conducted. A formal model is then developed that captures the dynamics of project development and includes explicitly the relationship between project sponsor and contractor.

1.3.1 Case Selection

The program of projects investigated was selected for the following reasons: First, as former employee of one of the major contractors engaged on the projects, I came into the study with a high degree of familiarity with the processes under investigation. Second, my years of experience in this realm and with these specific projects allowed for an accelerated appreciation and understanding of the challenges faced by senior project management and their consequent mental models and assumptions. Interviews with these individuals were made easier by my familiarity with the industry – I knew the secret handshakes! Finally, the nature of this program of projects, I believed, made these projects more susceptible to the dynamics under investigation in this thesis. Multiple project contracts[2] were used by the project sponsor to secure the capabilities and resources of the engineering service providers (contractors) required to execute on the

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[1] A "program" refers to the development of an infrastructure network. It can consist of a number of projects that are linked either through geography or utilization of shared resources.

[2] Multiple project contracts exist when the project sponsor awards a contract to a service provider that covers not just a single specific project, but rather a number of projects that are either conducted concurrently or in sequence. This bundling or projects heightens the perception of "what's at stake" during the contract negotiation.

projects forming the program. The bundling of projects into single larger contracts increased the financial implications for all parties involved in the bidding and award of the contracts. The contract structures themselves could therefore be expected to have received critical attention from all parties and thus represent the outcome of the firm's not inconsiderable expertise in generating and executing such agreements.

1.3.2 Case Investigation

A series of interviews were conducted with senior managers responsible for elements of each of the projects. The levels of management interviewed included Project General Managers (those responsible for the performance of the overall project), Facilities Managers (responsible for all of the physical systems being developed), Floating Systems Managers (responsible for the hull and structure of the floating platform) and Topsides Delivery Manager (responsible for the processing and accommodation structures mated to the hull of the floating system). In all, thirteen formal interviews were conducted, with a number of these being follow-up interviews, with nine key managers from the integrated oil company (project sponsor).

In addition to the formal interviews, presentations of the research were made to different sections of the sponsor's project community to promote further discussion and elicit new information. The communities engaged included members of the project management teams and representatives from the contract strategy development team. I was also able to attend a number of workshops organized by the contract strategy team. In these workshops a number of contracting strategies for engaging the engineering service providers were explored. Involvement in this process allowed for further understanding of the assumptions held by the project sponsors. Finally, internal reports documenting elements of a project's performance were made available for analysis. This data further helps establish the way in which the project sponsor evaluates the performance of the project and by default the performance of the contractors executing that project.

The data used for building the model, and conversations reflect the perspective of the energy company management. Therefore there is no formal representation from the contractor perspective, or from the functional levels of the project organization. This is mitigated to some degree by my own experiences in these roles and unofficial conversations with ex-colleagues.

1.3.3 A Formal Model

System dynamics was employed to build a formal model of the project structures being investigated. System dynamics modeling has enjoyed widespread success in the investigation and management of project and product development endeavors. The acceptance of this technique, and its established utility in this realm, make it the natural investigative tool. This thesis extends the traditional system dynamics project models by explicitly capturing the boundary between project sponsor and contractor. Previous examples have assumed that the project is enacted by an organization with singular financial objectives. This model breaks with that assumption. The formal model and the modeling process are described in detail in chapter six.

2.0 The Oil & Gas Industry

The energy industry is the world's largest with a private sector annual turnover in excess of $1.8 Trillion (measured in 2000)[3]. The global demand for marketed energy[4] is expected to increase from 404 quadrillion British thermal units (Btu) in 2001 to over 623 quadrillion Btu in 2025[5]. (See Figure 1 below). This represents an increase in excess of 54%.

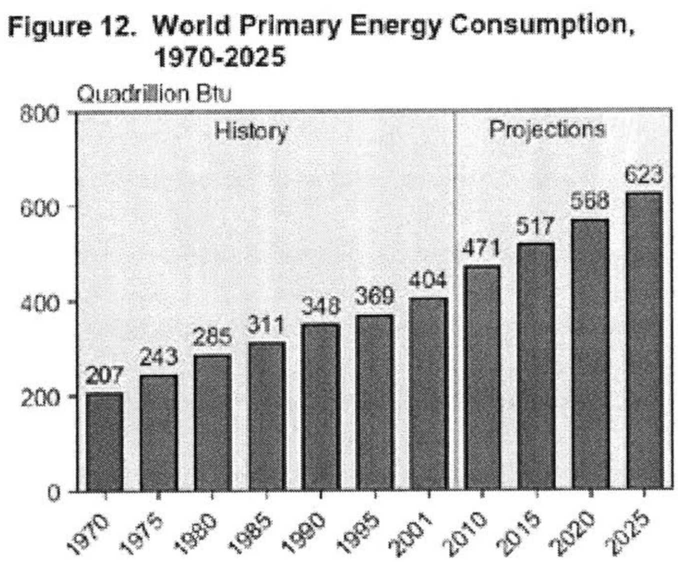

Figure 1. Global Primary Energy Consumption

To satisfy this demand the International Energy Agency estimates that investment in energy supply infrastructure between 2001 and 2030 is expected to top $16 trillion (in 2003 dollars)[6]. This investment is divided as shown in Figure 2 below.

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[3] "The slumbering giants awake?", *The Economist Energy Survey*, Feb 8th 2001, pg 6.
[4] International Energy Outlook 2004 (IEO2004),http://www.eia.doe.gov/oiaf/ieo/world.html. The projection for energy consumption is based only on marketable energy products
[5] Ibid.
[6] *World Energy Investment Outlook* – 2003, ISBN 92-64-01906-5 (2003), pg 41.

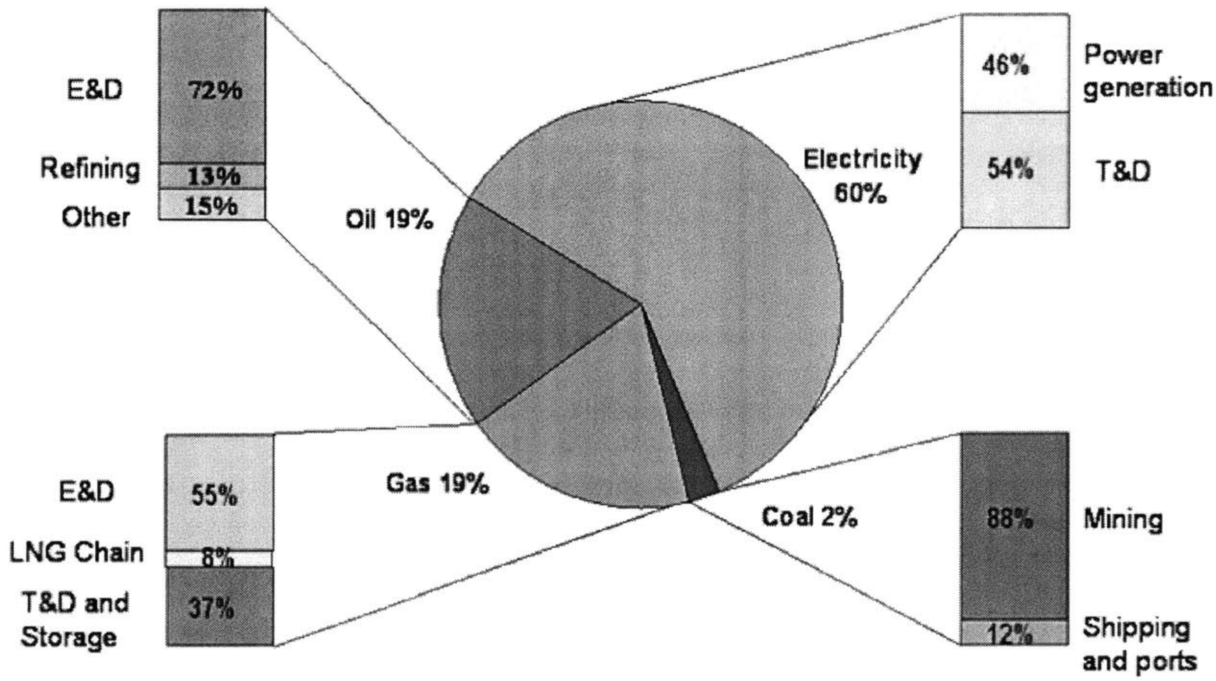

Figure 2. World Energy Investment (2001- 2030)

Note: E&D = Exploration and Development; T&D = Transmission and Distribution

As can be seen from Figure 2 above, oil and gas infrastructure investment alone accounts for 38% of the total. The investment in exploration and development activities for oil, gas and LNG (liquefied natural gas) will exceed $4.1 trillion over the period 2001 to 2030. This investment will be implemented through development projects with all the consequent risks of value erosion that result from poorly performing projects. A significant percentage of this investment will target offshore infrastructure, especially the deepwater fields. Any improvement in project execution in this environment results in significant financial upside for all involved.

2.1 Business Environment

2.1.1 Operators

To gain understanding of a key driver of corporate strategy in the oil and gas sector it is essential to be aware of the distribution of the worlds proven hydrocarbon reserves. The table below is drawn from the 2004 edition of the BP Statistical Review of World Energy which provides a comprehensive analysis of the state of the global energy market.

	World	NON-OPEC**	OECD	OPEC	Middle-East
Oil Reserves (Thousand Million BBL)	1147.0	178.8.8	85.8	882.0	726.6
Gas Reserves (Trillion Cubic Ft)	6204.9	N/A	546.5	N/A	2531.8
Oil Production (Million Tonnes)	3697.0	1717.0	997.5	1466.9	1093.7
Gas Production (Million Tonnes Oil Equiv)	2356.6	N/A	983.7	N/A	231.9

OECD: Organization for Economic Co-operation and Development
OPEC: Organization of the Petroleum Exporting Countries*

* Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates and Venezuela
** Excludes the Former Soviet Union states

Table 1: Global Oil and Gas Production, 2003

The integrated oil companies compete head to head in finding and producing hydrocarbons, and in the downstream segment for refining and selling petroleum products to the consumer. Each company invests heavily in technology in order to gain competitive advantage. The cost of producing oil and gas, measured in $/boe (barrel of oil equivalent), is a determinant of the company's success in the market place as it represents a significant portion of the fundamental underlying "cost-of-goods-sold". Infrastructure development (LEPs) makes up a significant part of the cost of producing the hydrocarbons, especially in the deepwater environment.

As can be seen from Table 1, the majority of the world's oil reserves are within the OPEC countries with the lions share found in the middle-east. Oil production is much more diverse however with nearly 50% of annual production taking place in non-OPEC countries. This reflects the presence of the independent oil-majors in West Africa, the Former Soviet Union, South East Asia, the Gulf of Mexico and the North Sea. The quest for new reserves to replace those currently in production is fundamental to ongoing operations for the independent oil majors. The oil producers are very much aware of the need to satisfy growing global demand for energy, and as such are investing heavily in the search for new sources, beyond those required for replacement stocks. Wall Street in particular pays close attention to the volume of proven reserves announced by the oil majors as a reflection of future earning potential and viability. However their access to many of worlds largest reserves is somewhat restricted (being either controlled by National Oil Companies or located within politically troublesome states). As a result the oil majors are turning to deepwater fields to satisfy the need for resources. Exploitation of reserves located in the deep waters of the regions such as the Gulf of Mexico requires massive investment in new infrastructure and a host of new technologies.

2.1.2 Engineering Service Providers

The resources, both human and material, needed to design, engineer, fabricate and install offshore oil and gas facilities are provided by the engineering service firms. These organizations are typically engaged by the project sponsor through a process of competitive bids. The service firms compete fiercely to win the contracts from the oil companies and in recent years have struggled financially as they have been forced to accept an increasing share of the project risk. The use of lump-sum EPIC (engineering, procurement, installation & commissioning) contracts has been favored by the oil majors as a mechanism to hold project costs down. At the same time the projects themselves have become significantly more demanding in terms of the uncertainties involved, both from a technology perspective and organizationally as the scale of the systems being built became ever larger. The imbalance between the risks accepted and the firm's ability to manage those risks has driven several close to bankruptcy and forced others to withdraw from EPIC contracts. In the environment of a limited market place, both for the number of client firms and the number of service firms, it is often the case that rival service firms will be partnered on a project while simultaneously competing to win the lions share of the next one. This very tight competitive environment forces firms to bid aggressively to win work from the oil majors, who are attempting to drive down the costs of the multi-billion dollar project investments they are making.

2.2 System Architecture

The systems required to exploit hydrocarbons from the world's deep ocean basins are very complex and they are required to carry out multiple functions:

- Drill the wells from which hydrocarbons are produced.
- Transport the well fluids in a safe and environmentally friendly way to the surface facility.
- Clean and partially refine the produced fluids for transport to shore.
- Store and then distribute the hydrocarbons to shore.
- Re-inject produced gasses and water as required into the reservoir beneath the ground.
- House and support the individuals required to operate the equipment and manage the processes.
- Provide the control and communication systems required to control, measure, direct, activate and respond to system changes.
- Achieve all of the above, while suspended on a man-made island located in over a mile of water, hundreds of miles from land, in such a way that the system can withstand the worst nature could throw at it in a 100 years. (The systems are designed to withstand the statistically generated 100 year storm state)

Needless to say new projects cost multiple billions of dollars to bring on stream and in the process require new technologies to be developed: new materials for the pipelines, new welding processes, new drilling techniques, new architectural forms for the massive floating structures required, new subsea components to be installed at depths of over a mile, and new installation and fabrication techniques.

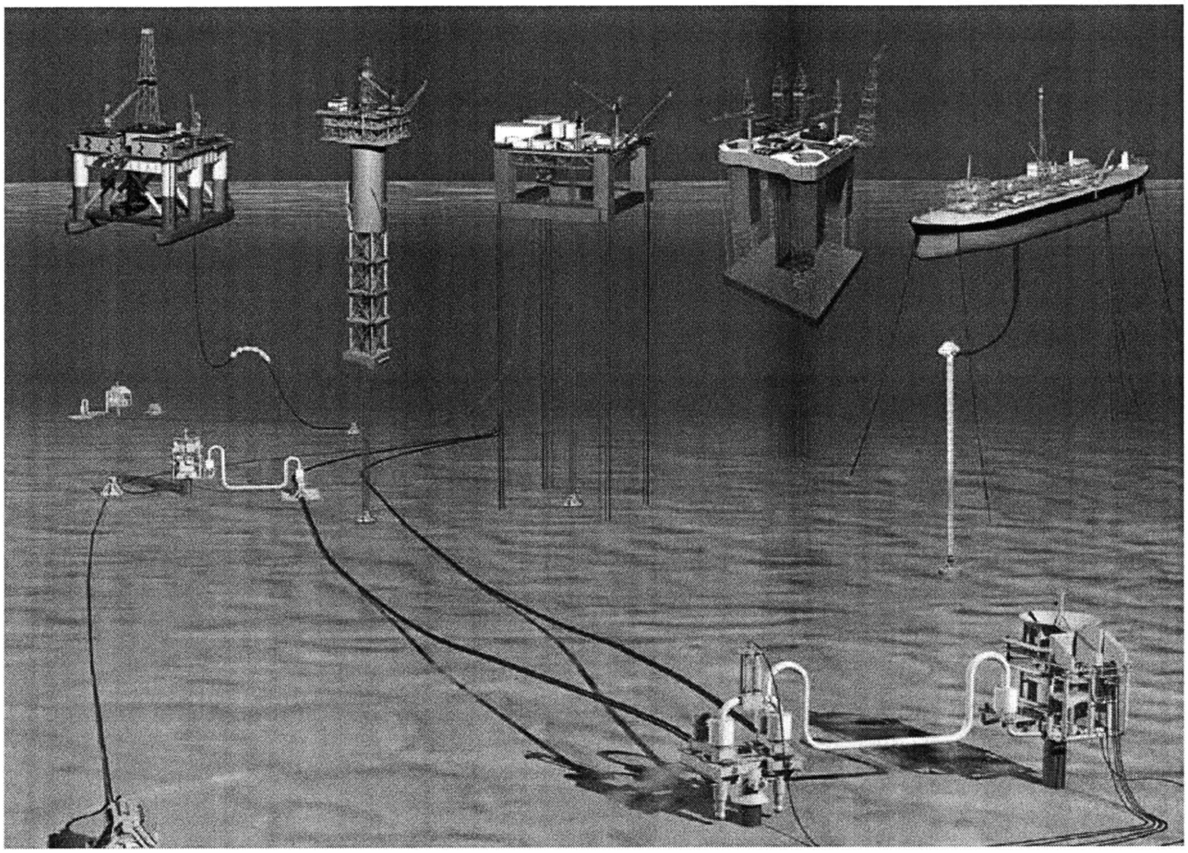

Figure 3. Examples of Platform Architectures

To develop these systems they are typically broken down into functional elements such as:

- Hull & Mooring– the floating structure that supports the equipment.
- Topsides – the process facility and accommodation, controls systems and potentially drilling system.
- Subsea – all the systems required to control the produced fluids from mudline to the surface facility. This includes components such as risers, flowlines, control and power umbilicals.
- Export – pipelines or offload system to transport the product to shore.

Each of these system elements are often engineered by different contractors as befits the technical specialization required. In addition each system's evolution from preliminary design, to detail design, procurement, fabrication and installation may be divided amongst different firms. For example, the hull may be designed by a firm in Sweden, manufactured by a Korean shipbuilding company, transported to the US and mated with the topsides by a US firm and finally installed offshore by another separate European company. The integration of all these firms and systems is enormously complex as evidenced by the following partial DSM.

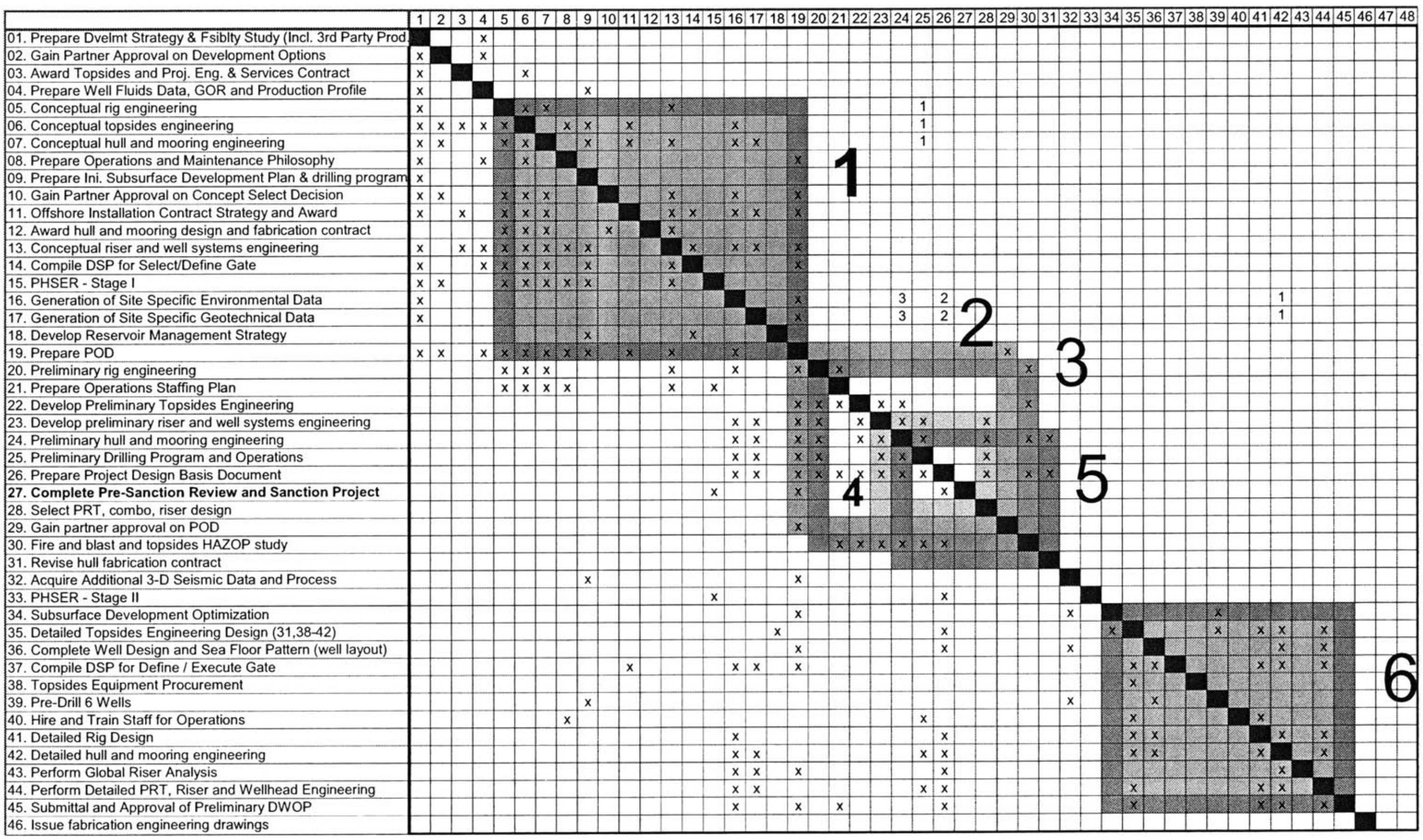

Figure 4. Oil and Gas Project Design Structure Matrix

Despite the "modularity" of contracting structure, the system itself is highly integral in nature being required to transfer and control vast amounts of mass and energy (Whitney, 2004), (the hydrocarbons may be produced from the wells at pressures between 10,000 psi and 15,000 psi and at temperatures exceeding 200 Deg F). For example, the design of the riser system (the pipes that are suspended from the floating platform that transport hydrocarbons from the seabed to the facility) requires design interfaces with the following systems:

- The hull – where the risers are placed affects the motion characteristics of the hull and the internal stress carrying requirements.
- The hull piping design – the interface with the piping determines the amount of thermal expansion allowance required, the loads placed on the hull piping and the dimensions of the hull piping (to match annulus dimensions for fluid flow characteristics).
- The flow assurance system – the control of the thermal properties and fluid dynamics of the product in the pipes (at certain temperatures and pressures the product can freeze due to entrapped water and block the system).
- The testing and controls system – all pipes are monitored for stress levels and performance to control for fatigue of the pipes.
- Fabrication and installation procedures and equipment – the design of the riser determines the capacity of the vessels required to fabricate and install the piping. This can then be a limiting factor on the riser design.

The list above is not, be any means, exhaustive. The operational aspects, maintenance, subsea design, architecture of well layouts, topsides design, testing requirements and many other elements are all related to the design and layout of this one system element. Obviously the development of such complex systems, with component counts exceeding those of commercial airliners by orders of magnitude, is enormously challenging. In the next section I explore the industry's success in delivering the systems described above.

2.3 Industry Performance

The track record of the oil and gas industry with respect to delivering major projects on schedule and budget has been disappointing. For example, a recent article reviewed a study of fourteen mega-projects (Merrow 2003) - eleven of them offshore developments - executed by the industry in the last 20 years. The outcomes of the survey were remarkable. The average cost growth was 46% over the authorization estimate, with half the sample exceeding 40% cost growth. The total value of this cost creep was $11.8 billion. Schedules also slipped by an average of 28%, with the seven worst projects – classified by the report as "dogs"[7] – slipping an astounding 39%. The report concluded that:

"Despite another 20 years of experience with large projects, you can't help but conclude that we have seen no material progress in the control of very large developments. The problematic projects here are reminiscent of many of the worst early North Sea developments...

...half of the projects must be described as failures from both a project management and business perspective."[8]

It is also significant to note that the report indicated that:

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[7] "Dogs" were those projects that had experienced cost growth exceeding 40%. These dogs were fully half the sample investigated.

[8] Merrow E., 2003, pp91

"*...facilities rather than well construction are the primary source of cost growth on the mega- projects.*"[9]

This is an important observation in that traditionally well construction has been perceived as an inherently risky activity due to the uncertainty of the drilling process. Managing complex facility development, design and construction processes however actually appears as the dominant area of risk.

Reviews from within the industry are not the only reference point for believing that the industry is doing a poor job of managing these complex projects. The investment community has also made its judgment. A recent equity research note issued by a Wall Street firm stated that they (the firm) would no longer offer specific coverage of the offshore construction/field development sector and offered the following rationale[10]:

"For several years, the industry has faced a difficult environment with excess capacity, irrational bidding practices on some fronts, poor project execution, generally unhealthy contractual terms, the building up of large outstanding claims, and significant order delays. We believe that these factors have reduced the justification for covering the offshore construction / field development niche as a dedicated sector."

This is not a singular assessment with other Wall Street investment firms echoing the sentiment:

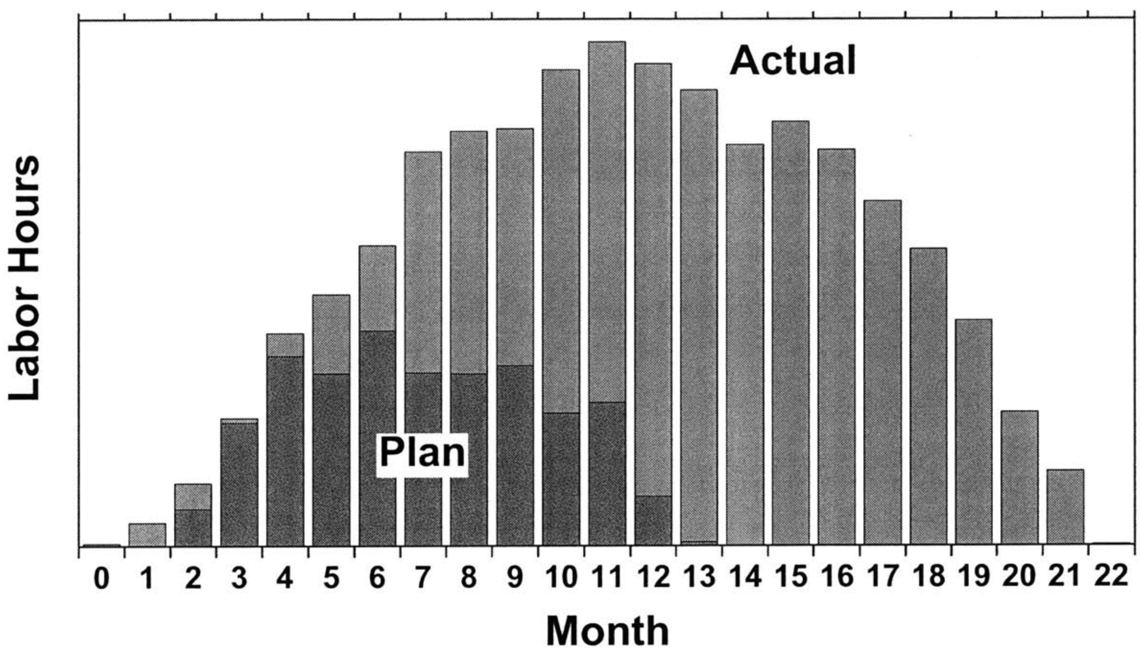
"Several structural issues in the sector have contributed to poor financial results over the last two years. The dominant negotiating position held by the major integrated oil companies, excess industry capacity and poor discipline exercised by several contractors

[9] Merrow E., 2003, pp 91.
[10] Morgan Keegan & Company, Inc. Members New York Stock Exchange Inc, equity research note issued November 14th 2003.

resulted in high-risk and unprofitable contracts that have plagued offshore construction companies."[11]

"...the industry must address the risk/reward equation associated with large EPIC (engineering, procurement, installation and commissioning) contracts. Several companies have already changed policies to avoid EPIC contracts or to limit the risks involved with contract terms. The willingness of major oil companies and the discipline of the construction industry participants as a whole to commit to structural changes in contracting could substantially lower the risk and volatility in earnings for the group."[12]

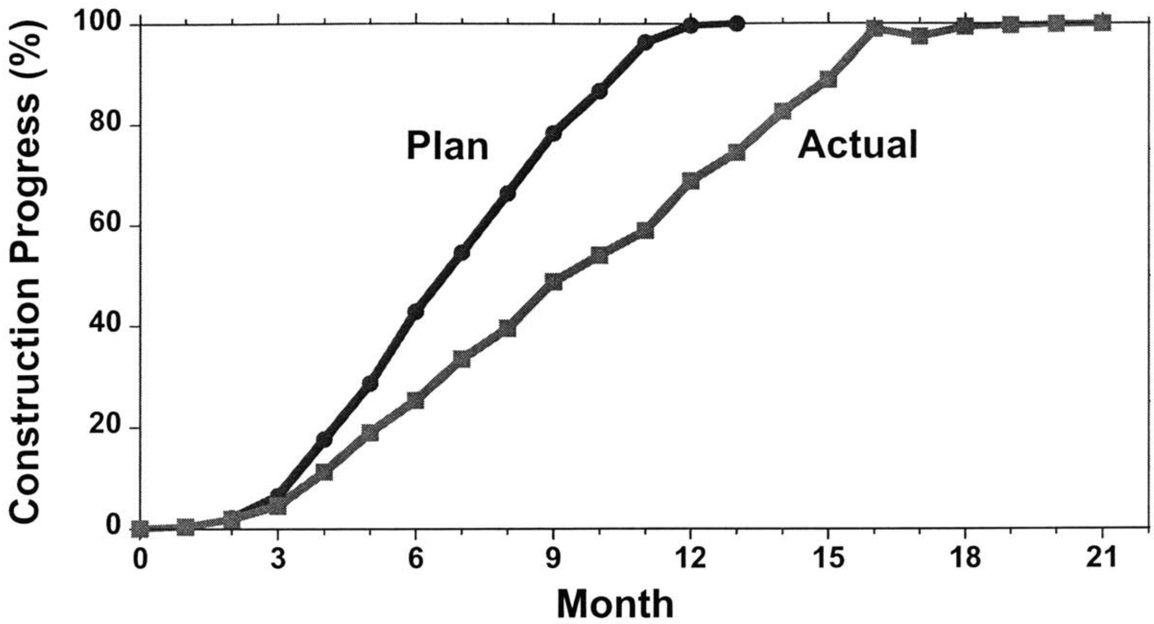
The project sponsors are not unaware of these issues and have ample evidence that many projects perform poorly. Consider the following chart created from data provided by an integrated oil company of an actual oil pipeline construction project.



Cumulative labor hours: 403% of plan

Figure 5. Oil Pipeline Construction – Labor Hours per Month

[11] Jeffries & Company Inc, Equity Research, Oil Services Group, *Offshore Construction: Riding Out the Turbulent Seas*, July 2003.
[12] Ibid.



*75% **apparently** complete by original deadline*

Actual duration: 162% of schedule

Figure 6. Oil Pipeline Construction – Construction Progress by Month

While the data presented above appears to represent an extreme worst case, the report quoted at the start of this chapter, and the assessment by Wall Street of the project execution industry seems to suggest that charts like the ones above are all too prevalent.

The question therefore needs to be asked: what is driving the poor performance of these projects (and thus the poor financial performance of the firms engaged), and what can the industry do to improve project execution? The next chapter reviews the literature that provides the framework in which we can craft a response to that challenging question.

3.0 Background and Literature (Foundation)

Project organizations are a feature of many industries, from energy, aerospace, shipbuilding and automotive to software and telecommunications. In all of these settings projects create challenges for the managers responsible for them, and for the organizations that execute them. These challenges manifest themselves in multiple aspects of the project, from project financing, the motivation of staff, management of product development processes to the design of appropriate metrics and incentive systems. Consequently the study of project based organizations, and the mechanisms that drive project performance in general, has generated a rich literature that cuts across a number of academic disciplines including organizational theory, economics, product development and system dynamics. This thesis draws upon aspects of that literature. In this chapter I will present an overview of some of these knowledge domains and establish the linkage between the existent theories in the appropriate knowledge area and the assumptions outlined in chapter one.

This thesis limits its investigation to projects which feature product systems that are essentially integral architectures. Integral systems are those that are "designed with the highest possible performance in mind"[13] and where "modifications to any one particular component or feature may require extensive redesign".[14] In this sense the systems under investigation in this thesis are definitively integral. Other definitions of integral architecture have been offered that relate to the decomposability of the system by

[13] Ulrich K, T., Eppinger S, D., 2000, pg 184.
[14] Ibid.

function: in integral architectures functions are spread across components resulting in more complex interfaces (Sosa, Eppinger and Rowles, 2000). This definition is familiar for categorizing systems by considering components within the system. In addition systems can be defined by how they share interfaces with other systems that form the product architecture; an external view of systems architecture (Sosa, Eppinger and Rowles, 2003). In this external view "integrative systems are those whose design interfaces span all or most of the systems that comprise the product due to their physically distributed or functionally integrative nature throughout the product."[15] Even momentary consideration of the design of offshore platforms and field developments would lead to their being characterized as integrative architectures, as the description in the preceding chapter shows. A further, and critical, determinant of systems architecture is provided by a consideration of system requirements from a mass and power transportation view. Whitney (2004) suggests that certain physical systems, typically mechanical ones that carry significant power, are constrained from utilizing modular architectures. The systems under development by the projects investigated here certainly qualify as mechanical systems carrying significant power.

The integral nature of the systems under development has important implications on the development process. As Novak points out "the more interconnected are the parts of a system, the more difficult it is to coordinate development"[16]. Communication between, and within teams, is essential for the successful development of complex systems. Wheelwright and Clark (1992) have emphasized the importance of communication with

[15] Sosa M, E., Eppinger S, D., Rowles C, M., 2003, pp 240.
[16] Novak s., Eppinger S, D., 2001, pp 190.

respect to improved project performance. As stated by Eppinger; "To assure that the entire system works together, the many sub-system development teams must work together".[17] Communication and information sharing is central to the development of complex systems, "team members deal with imprecise information and so must communicate to define problems or to reach consensus on the solution of a problem".[18] A number of elements are needed in support of fostering communication. Group cohesiveness has been described as factor in determining project outcomes. Keller (1986) noted that "cohesive project groups were able to achieve high project quality and able to meet their goals on budgets and schedules."[19] The literature thus certainly supports the notion that successful projects require significant investment in integration activities as stated in chapter one. It is therefore necessary to ask; what are the requirements for establishing this investment?

Generating cohesive teams requires interpersonal and inter-organizational trust. As noted by McAllister (1995), "researchers have argued that efficiency within complex systems of coordinated action is only possible when inter-dependent actors work together effectively. Trust between such actors is seen as a determining factor."[20] Investigations into the phenomena of virtual and distributed teams have also noted the importance of trust in generating the communication that is vital for project success. A recent study by McDonough III et al, (2001) into the use of globally distributed product development teams noted that "low levels of trust can have detrimental affects on the quality of

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[17] Eppinger S, D., 1997, pp 199.
[18] Sosa M, E., Eppinger S, D., Pich M, McKendrick D, G., Stout S, K., 2002, pp 46.
[19] Keller R, T., 1986, pp 723.
[20] McAllister D., 1995, pp 24.

communication and interpersonal relationships."[21] Trust becomes particularly important as a function of complexity. McAllister references Thompson (1967) in observing that "under conditions of uncertainty and complexity, requiring mutual adjustment, sustained effective coordinated action is only possible where there is mutual confidence or trust."[22]

Two principle forms of trust can be described: cognition based trust, grounded in individual assessments in relation to peer reliability and dependability, and affect based trust, grounded in notions of reciprocity founded by personal care and concern (McAllister 1995). These two forms of trust are highly coupled however and share the common attributes of reliability and dependability. Examples of these attributes can be interpreted as either expressions of effect based trust or as instances developing cognitive trust. In either case "reliability and dependability expectations must usually be met for trust based relationship to exist and develop, and evidence to the contrary provides a rational basis for withholding trust."[23] A Contractor falling behind schedule, or increasing the cost of a project through variation orders, can be interpreted as failing to meet the expectations of the project sponsor.

Trust as an attribute of organizational behavior is akin to the notion of relational contracts; informal agreements sustained by the value of future relationships (Baker, Gibbons and Murphy 2002). As noted by Baker et al (2002), "A relational contract thus allows the parties to utilize their detailed knowledge of their specific situation and to adapt to new information as it becomes available". The importance of relational contracts

[21] McDonough III E, F., Kahn K, B., Barczak G., 2001, pp 112.
[22] McAllister D., 1995, 25.
[23] Ibid, pg 26.

in the project environment is obvious. Of course, it is the formal contracts that establish the framework in which the relational contracts exist. In discussing non-traditional organizational forms such as joint ventures, alliances and virtual organizations Baker et al (2002) argued that "informal aspects, especially relational contracts, are important to the success of these non-traditional organizational forms. We also suspect that the formal and informal aspects not only co-exist but also interact, creating another opportunity to choose the former to facilitate the latter"[24]. This interaction was more forcefully argued by Gibbons (2002) in suggesting that firms explicitly use formal and relational contracts in tandem to achieve their desired outcomes in managing inter-firm relations.

In relationships between firms which use both informal (i.e relational) and formal contracts, the shift from the former to the latter indicates that the value of the future relationship is being re-evaluated. Reneging on the relational contract in favor of invoking the formal suggests that the value of the future relationship is less than the value of the immediate returns available from the formalized process. An example of this transition would be invoking the use of variation orders to manage changes within a project, in contrast to accommodating the change in a process of informal *quid pro quo*. This indicates a removal of trust with clear consequences on the willingness of parties to invest in trust based activities such as communication.

The field of system dynamics has been particularly engaged with trying to understand project behaviors. The nature of large scale projects, defined as they are by highly

[24] Baker, G., Gibbons, R., Murphy, K, J., 2002, pg 71

nonlinear relationships between components, multiple feedback processes and dynamic environments, makes system dynamics a particularly apt approach (Sterman 1992).

The persistence of poor project performance, despite the attention lavished on it, is often cited (e.g Ford and Sterman 1998, Ford and Sterman 2002, Lyneis, Cooper and Els 2001). A number of areas have been identified as causes for disappointing project performance:

- Lack of adequate front end loading.[25]
- Unrealistic schedules.
- Staffing. Either inadequate or poorly timed (i.e Brook's Law).
- Over use of overtime.
- Poor governance (Miller and Lessard 2000).
- Poor processes. (i.e a lack of clearly defined requirements, reviews, metrics)

The system dynamics approach to understanding project pathologies has focused on understanding the structure of projects that lead to schedule delays and cost overruns. The idea of the rework cycle is fundamental to this approach (e.g Cooper 1980, Abdell-Hamid 1991, Repenning 2001, Ford and Sterman 1998, 2002). A number of assumptions have characterized the systems dynamics models: First, that the tasks carried out by the organization are essentially homogenous, or are grouped into a few distinct categories. Essentially though, each task is not generally differentiable in terms of complexity, time to completion and skills required. This is clearly not true in real world projects, but at the

[25] Front end loading refers to the process of investing early in the project in activities that allow for areas of uncertainty to be adequately investigated and defined.

aggregate scale required for understanding the effects of delays, feedbacks and policy decisions the distinction proves generally unimportant. Second, the project organization was housed "under one roof". This is not to say that management was not distinct from staff engineers, or that there are not distinct phases of activities in a project (Ford and Sterman 2002, Black and Repenning 2001, Repenning 2001). Indeed a key behavior of the projects under investigation in the system dynamics literature has related to the impact of allocation of resources to different phases of the project. Rather the assumption of "under one roof" relates to the notion that the project model is contained within the boundary of one firm or enterprise. Divergent financial incentives between actors engaged in project execution have not been explicitly included previously.

The next chapter brings together the ideas explored above in the literature review. The dynamic interactions between the integral nature of the product system, the consequential need for investment in integration activities and the structural determinants of inter-organizational trust will be elaborated on. A simple causal loop model of the interconnections between these elements will be presented in a prelude to developing the formal system dynamics model in chapter six.

4.0 Why projects have problems.

It is important to recall an assumption stated in the introduction: the firms will act to create value (as they perceive it) for their shareholders. For the contractors the creation of value is achieved through a variety of contractual mechanisms. The first is the agreed rates or lump sum value of the project. The project sponsor and contractors agree a price for provision of services, the scope of services being set out in the contract documents. A second mechanism for deriving value from the contract is the use of variation orders, sometimes known as change orders. This mechanism is provided in contracts as, for all but the most trivial of projects, there is uncertainty surrounding the scope. This mechanism allows for changes to be made to the contract scope and additional costs calculated. Contractors are able to use these mechanisms to generate additional revenue from the project. In very large and complex projects there usually exists a certain unavoidable amount of ambiguity to the contractual terms. It is almost received wisdom amongst project sponsors that the contractors use variation orders as a primary source of revenue. The third mechanism of value creation is developing a relationship that leads to future work (relational contracts). This is often paid lip service to, but it is extremely hard to quantify the value of these relationships when the project sponsors almost always use competitive bids to select contractors. The variation order revenue mechanism can be described by the causal loop below.

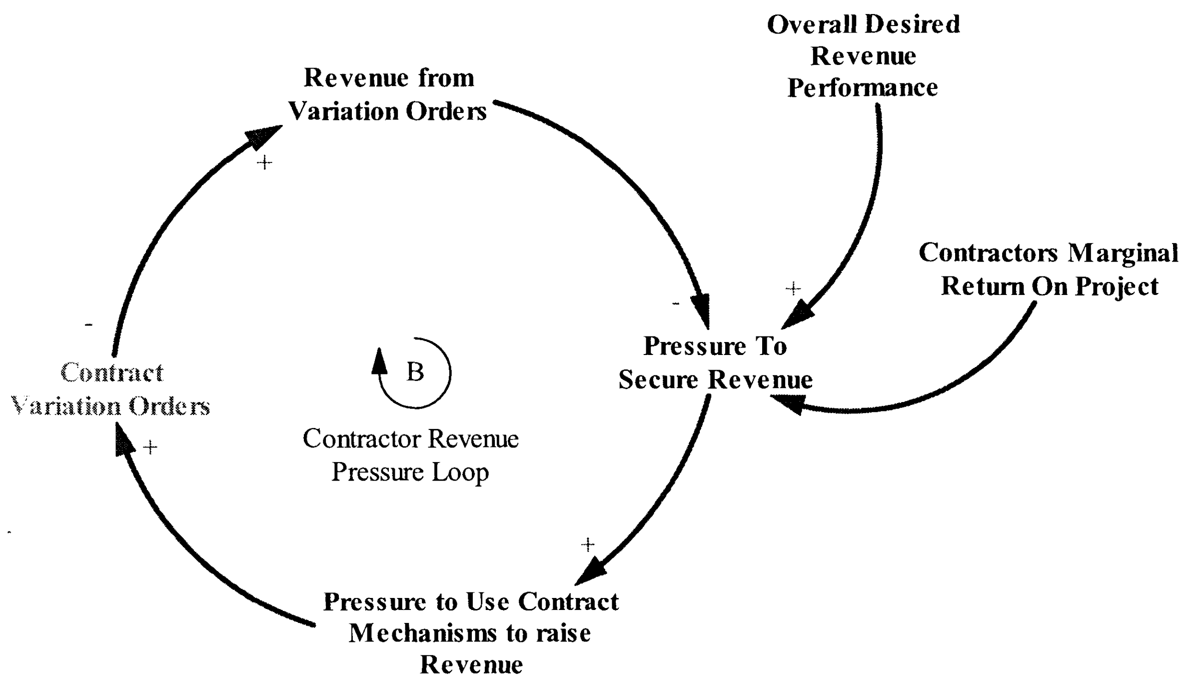

Figure 7. Variation Order – Revenue Loop

The loop above captures the contractor's use of variation orders to derive revenue on a particular project. When a gap exists between the desired financial performance for the firm and the return achieved on a specific project this leads to pressure to secure revenue on that project. This in turn leads to pressure to use contract mechanisms to raise revenue. The use of variations orders (VOs) consequently increases. As VOs increase revenue is generated from the project. This helps to close the gap between expected and delivered performance. A balancing loop is the consequence. Of course, the use of variation orders does not just deliver revenue. Other consequences exist.

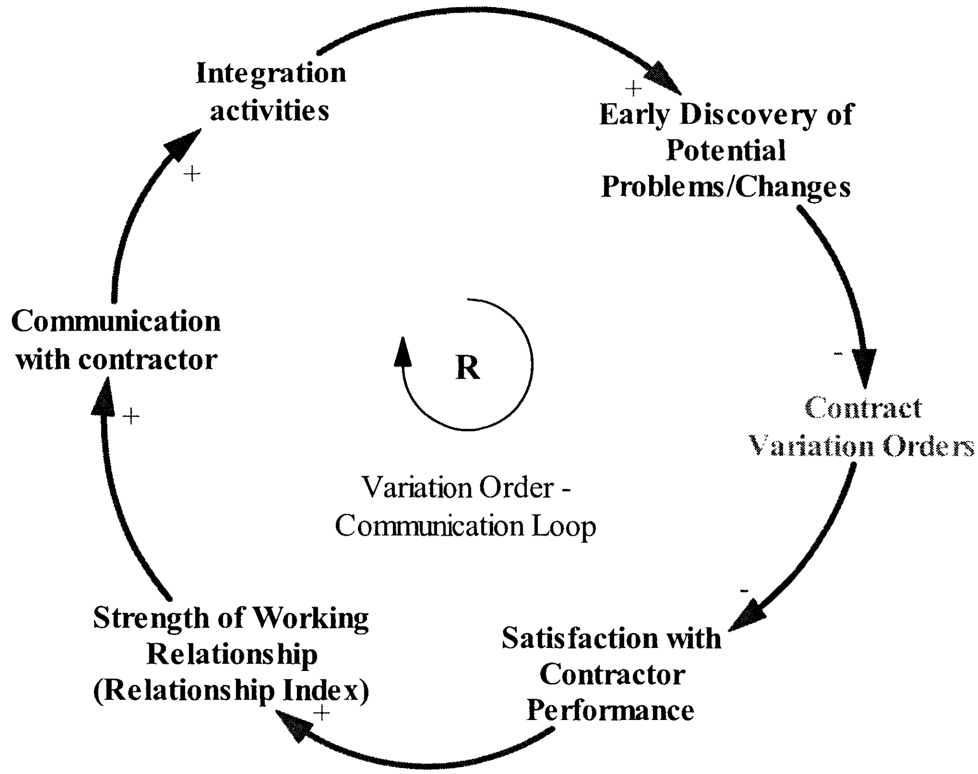

Figure 8. Variation Order - Communication Loop

The causal loop shown above indicates the interaction between communication, integration and variation orders. Variation orders represent additional costs for the project sponsor and, when used, are likely to reduce the level of satisfaction the sponsor has with the contractor's performance. This is easy to understand if we recognize that the sponsor's managers are typically assessed by their ability to deliver a project *on budget.* Variation orders usually hamper that ability. Satisfaction with the contractor's performance is correlated with the strength of the working relationship that exists between the contractor(s) and the sponsor. As discussed in Chapter 3 the use of formal contract mechanisms (VOs) indicate a shift away from a relational contract form. As the relationship between the contractor and sponsor is damaged by the VOs, the incentive to invest in trust based processes such as communication is diminished.

A necessary consequence of reduced communication is reduced investment in integration activities (meetings, design reviews etc). In highly integral architectures a reduction in these activities leads to an increase in errors as fewer of the complex interactions between sub-systems are validated amongst the sponsor-contractor design teams. Finding the sources of variations (rework errors) earlier allows for the reduction in variation orders. As can be seen from the reinforcing loop described above, a consequence of using variation orders is a damaged relationship between project teams, reduced communication and integration activities and hence more of the errors that create variation orders! Variation orders become a link between the need to secure revenue and a damaged relationship between project sponsor and contractor.

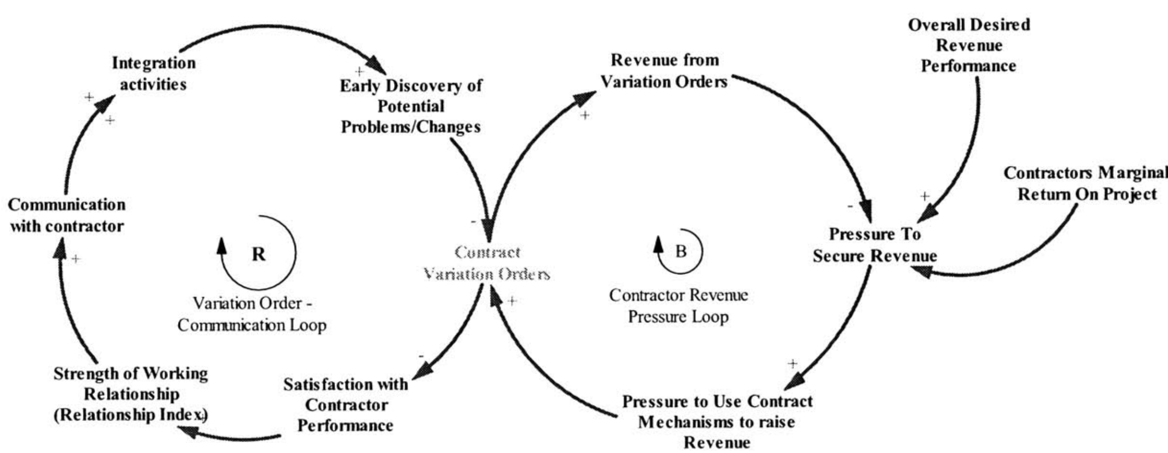

Figure 9. Variation Orders: A Linking Mechanism

Variation orders don't just impact the time devoted to integration activities via their effect on the sponsor/contractor relationship. Variation orders also generate additional work, or tasks, for the project team. Each variation order, at a minimum, requires the development of documentation to support the claim, auditing, tracking, attendance of meetings to resolve discrepancies, meetings to determine anticipated costs and impacts on the project schedule and budget, in addition to actually carrying out the project tasks that are identified in the VO. Thus the variation orders also impact the performance of the project by generating additional tasks and additional resource pressures on the project. This is illustrated below:

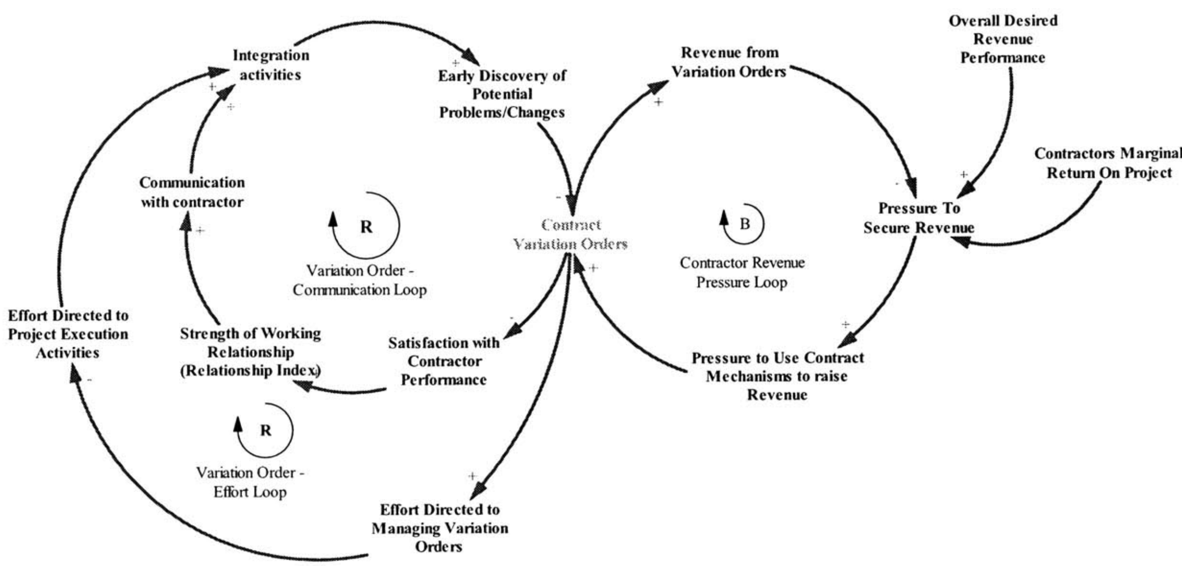

Figure 10. Variation Order – Effort Loop

As discussed above, variation orders required effort to develop and manage. This work takes time and effort away from the tasks that make up the original project scope. More work means less resources (time, people) are available to invest in time consuming activities such as the critical integration processes. The consequence of that remains as described earlier. Here again we see that the use of variation orders in fact leads to, again, more errors and more variation orders. Now we can see two reinforcing loops acting in concert as a consequence. However, the impact of variation orders does not end here.

The variation orders generate tasks that require resources. This is made clear above. The outcome of that is that the existing resources get spread more thinly and integration activities suffer. A further consequence is that pressure builds to service this additional work load through the acquisition of additional resources. From the contractor's perspective the ability to staff the project has been determined, in part, by the terms (profit margins, value of the bid etc) agreed for the original contract. Bringing more personnel onto the project requires a budget to support that action. This can lead to additional pressure on the project to deliver revenue to help pay for the additional resources the variation orders generated. This mechanism is particularly apparent when the contractor is already resource constrained. In this environment the contractor will look to hire non-staff engineers (confusingly called *contractors* by the industry) to supplement their staff. These day-rate staff, (as I will term them) are typically more expensive than full time staff employees (for a number of reasons I will not explore in this thesis). The additional cost of expensive staff places pressure on the project to use variation orders to secure revenue. Another reinforcing loop exists.

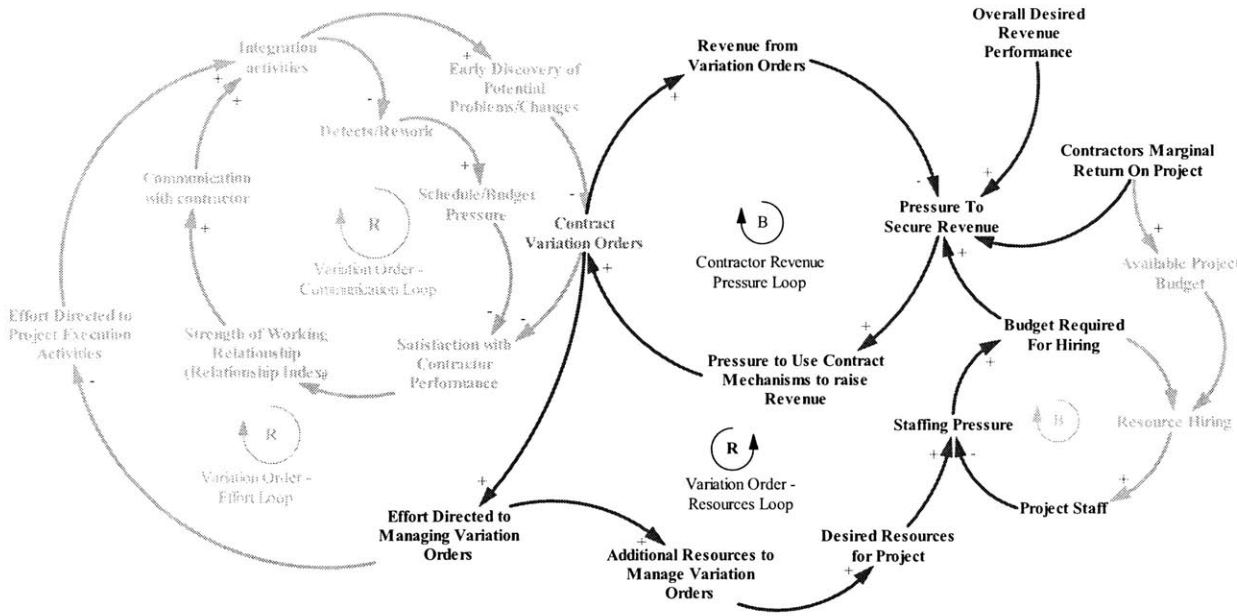

Figure 11. Variation Order – Resources Loop

It is clear that once we put all of these feedback structures together that the decision to use variation orders has a number of consequences for the execution of the project. What we need to develop is some appreciation for the scale of these consequences. We would like to be able to represent and quantify, to a first order, the impact of the decision to use variation orders. It is also necessary to see how in a given project structure the use of variation orders is shaped by elements of the project such as schedule pressure, returns on the project and the strength of the relationship. It is also necessary to understand the drivers of variation use in the first place and to see how the use of alternative policies by the project sponsor could mitigate their use. A formal model of the system shown below is developed in chapter six to explore the questions just enunciated.

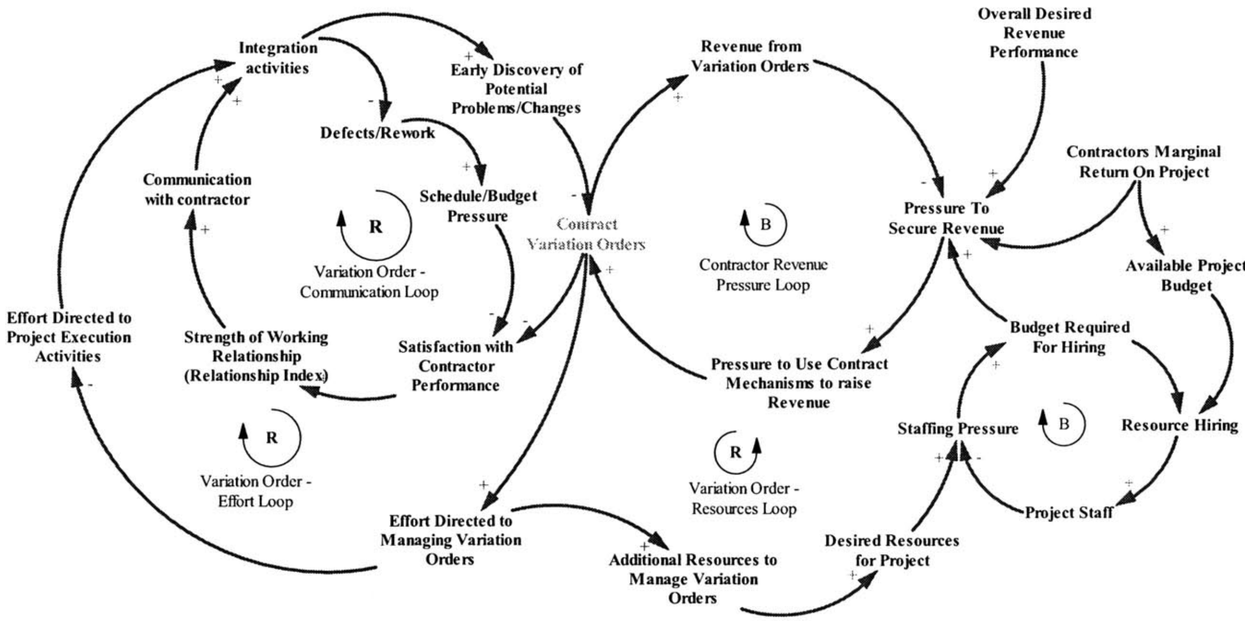

Figure 12. Variation Order Feedback Mechanisms

5.0 Project Case Study

Large oil and gas projects evolve over several years and the "Milton" development, the basis of the case study, was no exception. This project was one of a number of field developments that were being executed by the project sponsor, "Big Oil Corp". The other major projects were "Lumbergh", a North Sea project "Swingline" and a West African project "Samir". Each represented significant investment, and risk, for the project sponsor and the engineering contractors engaged on the project.

5.1 Program Strategy: Milton, Swingline, Lumbergh and Samir

Toward the early 1990's "Big Oil Corp" had a portfolio of promising oil and gas fields located across the globe that they wished to develop. It was anticipated that developing these projects would involve the commitment of a significant portion of the industry's capabilities. In several niche technology and service areas (such as offshore installation, pipe manufacturing, and shipyards) a shortage of the assets required to execute the projects was identified and a contracting strategy to mitigate these pinch points was developed. In an effort to secure access to the human and physical resources needed, "Big Oil" developed a "program" contract strategy. This approach awarded contracts to the engineering service providers not for each project, but for the portfolio of projects. Each project within the program was a major investment requiring sustained effort over multiple years, and the program strategy represented a departure from the industry norm.

The strategy appeared to offer a couple of advantages over a traditional approach. First, the program guaranteed supply of the services that were required for the projects. Second, in return for delivering a guaranteed stream of work for the contractors over multiple years the engineering firms would reduce the cost of their services. It was expected that these savings would be made possible by the repetition of key design elements amongst the projects and hence create learning curves for both the sponsor and contractor teams. As one senior manager involved with the development of this approach put it, the firm would approach the set of projects:

"rather than a series of one off projects…aggregate volume, drive for economies of scale and this lets us have an agenda around standardization"

As we shall see, the reality unfolded somewhat differently than was anticipated. In fact the implementation of the program strategy may have contributed to a number of problems that the projects experienced. To simplify the case study a little, just one of the projects will be focused on. The chart below lays out some critical events related to the Milton development.

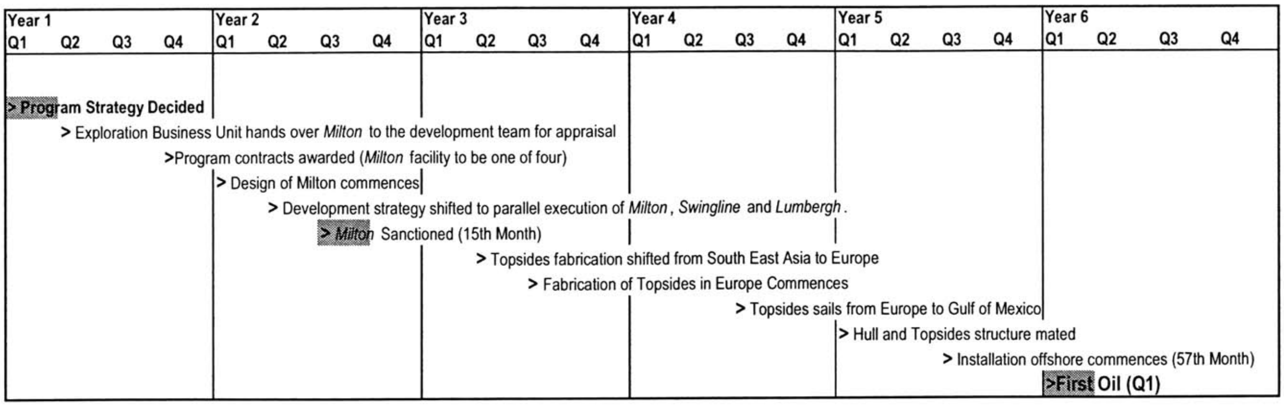

Figure 13. Timeline of *Milton* Topsides Contract and Project Execution

While one view was that economies of scale, and repeatable work, was enough to help lower the cost of the projects, another view was that the scale of the work enabled Big Oil to take a strong bargaining position in the market place. The portfolio of projects, when offered into the market as a single package, represented a significant portion of the available work for the contractors. They could ill afford to not pursue the work vigorously. From Big Oil's perspective the use of scale to create bargaining leverage was justified by the recognition that, as stated by one facility manager, *"there are a lot of people in this company that think that contractors are trying to rob us blind"*.

In the fourth quarter of Year 1 the first program contracts were awarded to key contractors. These were established despite the fact that very little preliminary design had taken place, indeed, even before projects (such as Milton) had even been officially sanctioned. The contracts were established based on "generic" engineering designs. At the time this was a crucial step in the contract strategy of securing the required resources. It was known that other major integrated oil and gas firms were planning significant projects and thus Big Oil decided to move fast on the contract strategy before their competitors tied up available resources. Front end loading was sacrificed in order to achieve the required outcome. In retrospect many senior managers now believe that this decision was a significant contributor to the later problems faced by many of the projects, particularly Milton and the North Sea development Swingline. All the projects faced numerous changes to their designs late in the development cycle and carried the costs of the resulting variation orders.

The contracting approach had been, in part, predicated on the notion that the execution of the developments would follow a pattern of "design one and build four" or as one manager put it: *"we were going to be like Henry Ford and build the same type of facility four times"*. However, by the second quarter of Year 2 the corporate drivers for the program of projects had changed. Executive management at Big Oil determined that the schedule for the projects should be compressed from a sequenced approach to a parallel one. This was driven by the Board of Big Oil wanting to firstly signal Wall Street investors that the firm was committed to developing these fields at a "best-in-class" pace, and secondly, to fill what they perceived as a potential gap in the firm's reserves and production profile towards the middle of the decade. This required a fundamental shift in the contracting approach, best summed up by one project manager as: *" a complete change in strategy from sequenced to let's do 'em all at once"*. This also precipitated pressure to move the individual projects forward and *"rush to sanction before we were ready because of artificially induced deadlines"*.

Design work on Milton commenced early in Year 2, shortly after the program contracts were awarded and before the change in contract schedule was announced. It wasn't until the third quarter of Year 2 that Milton was officially sanctioned. At about this time the project teams for Samir and Lumbergh, each under pressure to accelerate development schedules, and having commenced preliminary design work, recognized that the extraction of hydrocarbons from their fields required fundamentally different facilities to that needed for Milton and Swingline. The system architecture of the platforms and subsea systems needed to change.

The contractors were now facing not one coordinated program of similar projects but essentially four competing unique projects. Consequently the existing contracting framework and working relationships came under pressure and problems began to materialize. The contractors had *"given Big Oil a 'discount' on additional facilities"* with an expectation of repeatability, which was now a diminishing possibility. In addition the contractors were placed in the situation of having to deal with four separate project teams from Big Oil, each of which was demanding that their specific needs be met. The construction of the topsides for Milton exemplifies some of the challenges that appeared.

The fabrication of the topsides and deck structure for Milton (the major structural element that supports and incorporates the production facilities) had been awarded to a South East Asian fabrication yard. However, the performance of the Asian yard did not meet expectations, and it was felt that their low bid price (while attractive enough to win them the contract) contributed to their lack of flexibility and capability. The fabrication yard was not able to respond to the requirements for the reduced schedule and in an effort to accelerate execution by 3 months the fabrication was shifted to a European yard towards the middle of Year 3.

Unfortunately the European fabrication yard also struggled to deliver the topsides to schedule. Indeed, the aimed for 3 months acceleration, and more, was lost as the contractor ran into unexpected design and fabrication challenges creating cost overruns and delays. The European yard was in fact a subsidiary of one of the contractors selected for the program contracts and as the full complexity of the Milton design became apparent they used variation orders extensively. In addition the Swingline project was also being fabricated by the same contractor and the two Big Oil projects were competing with each other for a limited pool of resources. The topsides experience was not unique however, a second contractor on the Milton project also experienced difficulties in meeting their obligations.

The structure for Milton was being fabricated in two sections, with the second section being constructed in the United States. This contract had also been awarded as part of the program strategy. This major element of the project also suffered from significant cost overruns. The contract had been awarded to a firm whose contract bid price was "very attractive" from Big Oils perspective. However, problems occurred because, as was stated during an interview with one of the Big Oil senior managers *"they told us that they had the labor to do the job, but they didn't"*. In the end Big Oil had to step in and effectively take over the detail responsibility for managing the job. By the completion of that phase of the project, fabrication of the second section had consumed double the man hours planned!

Towards the end of summer of Year 4 the topsides left Europe for the United States. This was several months later than planned and the journey now had to take place during the hurricane season in the Gulf of Mexico; an extremely risky time to attempt such a transit. Fortunately the project was lucky and the topsides arrived without further problems. The mating of the two sections suffered some additional delays and it was not until the third quarter of Year 5 that the offshore installation of Milton finally commenced. In the opening months of Year 6 Milton delivered first oil and the project was completed.

5.2 Milton and the Program: What went wrong

The Milton facility, from an engineering standpoint, is a tremendous achievement. It features several technical firsts and, for its type, is one of the largest facilities in the world. However, schedule delays, changed contractors and a number of revisions to the design, resulted in significant escalation to the cost of Milton. In the end the project was delivered 5 months late and nearly 50% over budget. The problems that Milton experienced were created by the confluence of a number of factors.

<u>Inadequate front end loading</u>.

It is well understood that projects suffer when inadequate front end loading (preliminary design and analysis to understand the project) is carried out. The study of mega-projects cited in chapter two highlighted a lack of front end loading (FEL) as a contributing factor in the performance of the "dog" projects (Merrow 2003). The Big Oil program projects suffered from a lack of FEL. In order to secure the resources they needed the company rushed ahead with a contract strategy based on extremely sparse information. After the contracts were in place, and once adequate work had been done, it was discovered that each field was really quite different and required unique solutions. The "design one, build four" paradigm was wholly inappropriate. Unfortunately by the time this was realized it was too late. The projects had commenced, contracts were in place, and the only available option was to accept the cost and delays associated with changes.

Accelerated schedule.

The mega-project study also notes the deleterious impact of accelerated schedules on large complex projects. The study states that:

"time pressure discourages full and effective team development while ironically making it more important. This leads us to the clear conclusion that the proximate cause of failure in mega-field development is schedule pressure."[26]

"With a single exception, the successful projects were not schedule-driven. This meant the projects' schedules were derivative of the data needed to proceed rather than driven by arbitrary (from the project's viewpoint) end dates."[27]

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[26] Merrow E., 2003, pp 92.
[27] Ibid, pp 92.

The Big Oil projects experienced a great deal of schedule pressure. Accelerating the schedule played a role in curtailing the FEL and then collapsing the planned sequenced development schedule to a parallel one. This meant that any opportunity for creating a learning curve amongst the firms and their respective employees was lost. Everyone was learning at the same time with no opportunity to deliver improvement to the next project-in-line. The schedule pressure also damaged the relationships between the firms and made the process of developing truly integrated project teams that much harder.

Contract strategy changes.

The shift from a sequenced program approach to a parallel individual project approach dramatically changed the dynamics of the projects. Each project General Manager had incentives to deliver his or her project on schedule and budget. This inevitably led to each project pushing their claims of "priority needs" onto the contractors. The contractors, under pressure to perform to an accelerated schedule, and with an increased work load due to design changes and more parallel activities, struggled to cope. The result was delays, variation orders and cost escalation.

Organizational design.

The shift in contract strategy, and the accelerated schedule alone would have taxed the relationship between Big Oil and their contractors. This strain was compounded by the introduction of design changes as the real nature of the fields revealed themselves. Over and above that was the fact that Big Oil had not adequately developed an organization to deal with the four parallel projects. Under the original program approach organizational capability had been established. With the shift in contracting approach this capability was no longer deemed necessary and the capability was removed. The contractors were left without a mechanism to adjudicate between competing interests, all of whom were Big Oil representatives. It followed that someone (or some team) was *always* going to face a disappointing outcome from interaction with the contractor. This was a further blow to the contractor relationships and consequently the project suffered.

However, over and above these challenges, one theme emerged from the case study that determined the success or failure of projects: relationships. This theme can best be summed up by a statement from one of the senior project managers from Swingline:

"building success means making your contractors succeed"

The relationships between Big Oil and its contractors determine the project outcomes. The issues raised above help shape the strength and effectiveness of that relationship. Dealing with schedule pressure, or accommodating changes, effectively requires strong relationships. The problems experienced on Milton with the fabrication yard contractors may well have been avoidable had a strong relationship existed between the firms. As a senior manager from Milton said:

"You can't write in everything (into the contract)*....you need to build a partnership... ....because it counts when you have problems"*

Exploring the reasons for failure or success of major projects requires an understanding of how relationships shape the execution of those projects. Chapter six, in proposing a system dynamics model of this environment, begins that exploration.

6.0 Project Model

The case study illustrates the importance of relationships between project sponsors and contractors in delivering major project successfully. Virtually all major product systems are developed through extended networks of organizations. The causal loops presented in Chapter four identified one mechanism, variation orders, that exist between firms and identified potential impacts derived from their use. The next step was to build a formal model of these project relationships. System dynamics was used to build a project model and was created using Vensim™ software.

6.1 Model Structure

A key structure in most project models is the rework cycle, which is illustrated in Figure 12 below.[28] This structure was first developed by Pugh-Roberts Associates (Sterman 2000) in relation to the Ingalls Shipyard claim and, as described in chapter three, it has subsequently been revised and refined through many different applications (Abdell-Hamid 1991, Repenning 2001, Ford and Sterman 1998, 2002).

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[28] Lyneis J.M., Cooper K.G., Els S.A., 2001, pp 245.

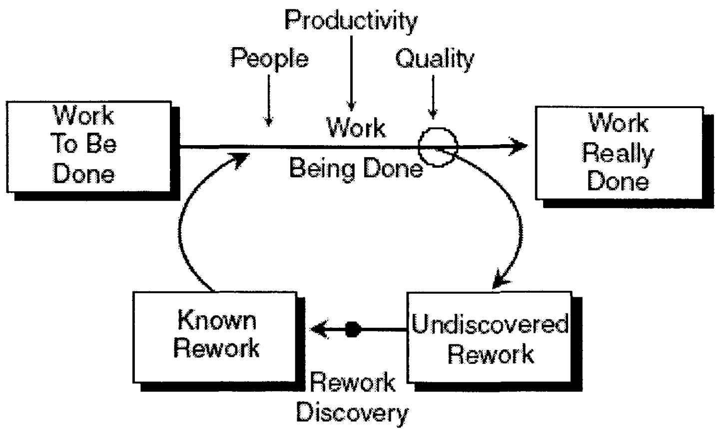

Figure 14. The Rework Cycle Structure

The essential feature of the rework cycle is that the project begins with a stock of work, or tasks, to do: *Work To Be Done*. Work is then carried out at a rate determined by the number of people on the project and the productivity of those people. The quality of the *Work Being Done* then determines whether the work is *Work Really Done* or *Undiscovered Rework*. The stock of *Undiscovered Rework* is reduced over time as the rework is discovered at the *Rework Discovery* rate at which point it moves into the stock of *Known Rework* – essentially the tasks or work that need to be redone to match the required quality. These tasks then move back into the stock of *Work To Be Done*.

The rework cycle constructed for this thesis is somewhat different from the version illustrated above.

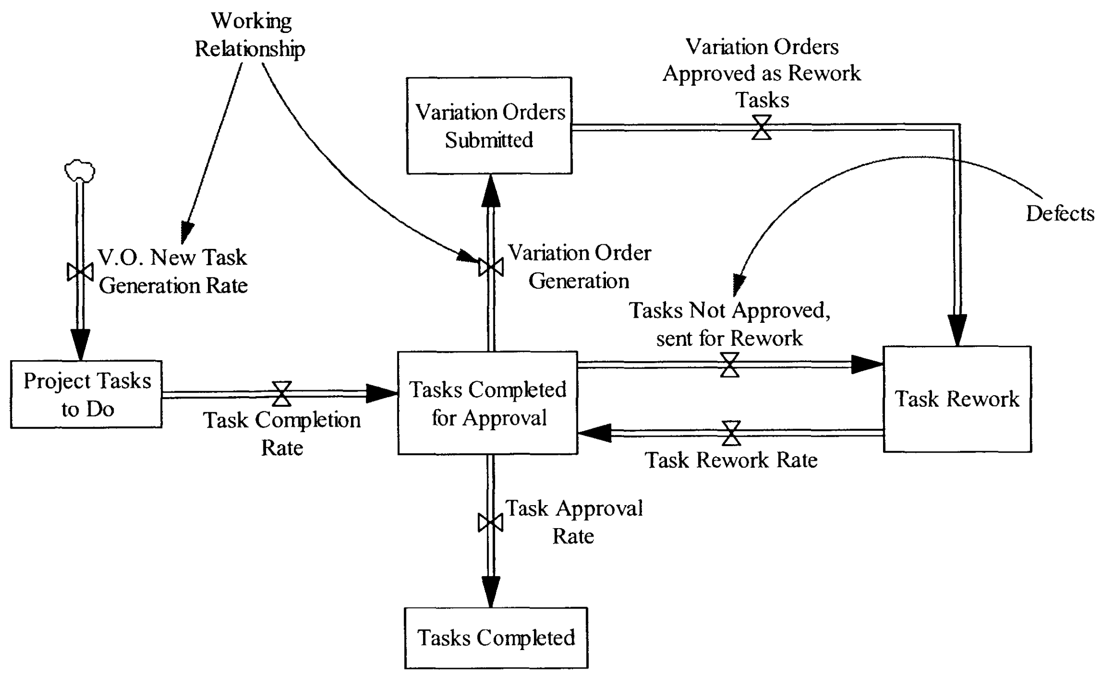

Figure 15. Contract Model Rework Cycle

In the thesis model the rework cycle is somewhat simplified by removing the stock of *Unknown Rework.* This removes a delay in processing and executing the rework tasks, making the project model more efficient (thus making the model conservative in its behavior) while maintaining the essential feature of distinguishing between work to do, work completed correctly and rework. The thesis model adds the variation order cycle to capture this feature of interest. Tasks with defects move either to the stock of *Task Rework* or *Variation Orders Submitted.* Variation orders are then approved as rework tasks and move to the stock of *Task Rework.* A certain percentage of these *Variation Orders Approved as Rework Tasks* also generate new tasks which enter the stock of *Project Tasks to Do* at the rate of *V.O New Task Generation Rate.*

The variation order cycle captures the process whereby a certain percentage of tasks that are identified as rework will generate variation orders. As discussed in chapter four, no contract can completely specify the tasks to be performed. As a result some rework tasks can be subject to claims (variation orders for more money and time associated with a task that now appears more complex than originally thought, for example) by the contractor. In addition some of these variation orders generate new tasks that had not previously been within the contractor's scope.

A further important feature of the thesis model is the linking of integration time to the *New Work Defects Fraction*. In previous models, defect or error rates are typically determined by variables such as staff morale, fatigue, experience and schedule pressure. The concept is that unmotivated, tired, inexperienced or harried staff makes mistakes in executing the tasks leading to defects. These phenomena are well understood and represented in numerous project models. The thesis model however captures the idea that a critical determinant of project success for complex systems is communication. When teams in a complex project do not invest in integration activities (meetings, design reviews, timely transfer of design specifications etc) elements of the project design diverge and errors are introduced. Thus the *New Work Defects Fraction* is a function of the *Fraction Time on Integration.*

The variation order cycle also impacts the relationship between project sponsor and contractor and the financial performance of the project (as discussed in chapter four). The model therefore also measures the financial performance of the contractor and this performance determines in part the *Percent of Rework Tasks submitted as Variation Orders by Contractor*, *Desired Full Time Staff* and the *Initial Full Time Staff.* Completing the key structural elements of the model is the *Relationship Index*. This composite variable captures the strength of the working relationship between the sponsor and contractor and is a function of the *Sustained Schedule Pressure*, the *Actual Staff to Planned Staff Ratio* and the *Actual VO to Expected VO Ratio*. The *Relationship Index* variable then determines in part the *Fraction Time on Integration* and *Percent of Rework Tasks submitted as Variation Orders by Contractor*. These relationships model the reinforcing loop "Variation Order – Communication Loop" presented in chapter four.

In addition to the core structural elements outlined above, a number of other important structures exist. The model includes structures for the hiring of staff and the build-up of schedule pressure. A full model description, including formulations and model views is available in Appendix A.

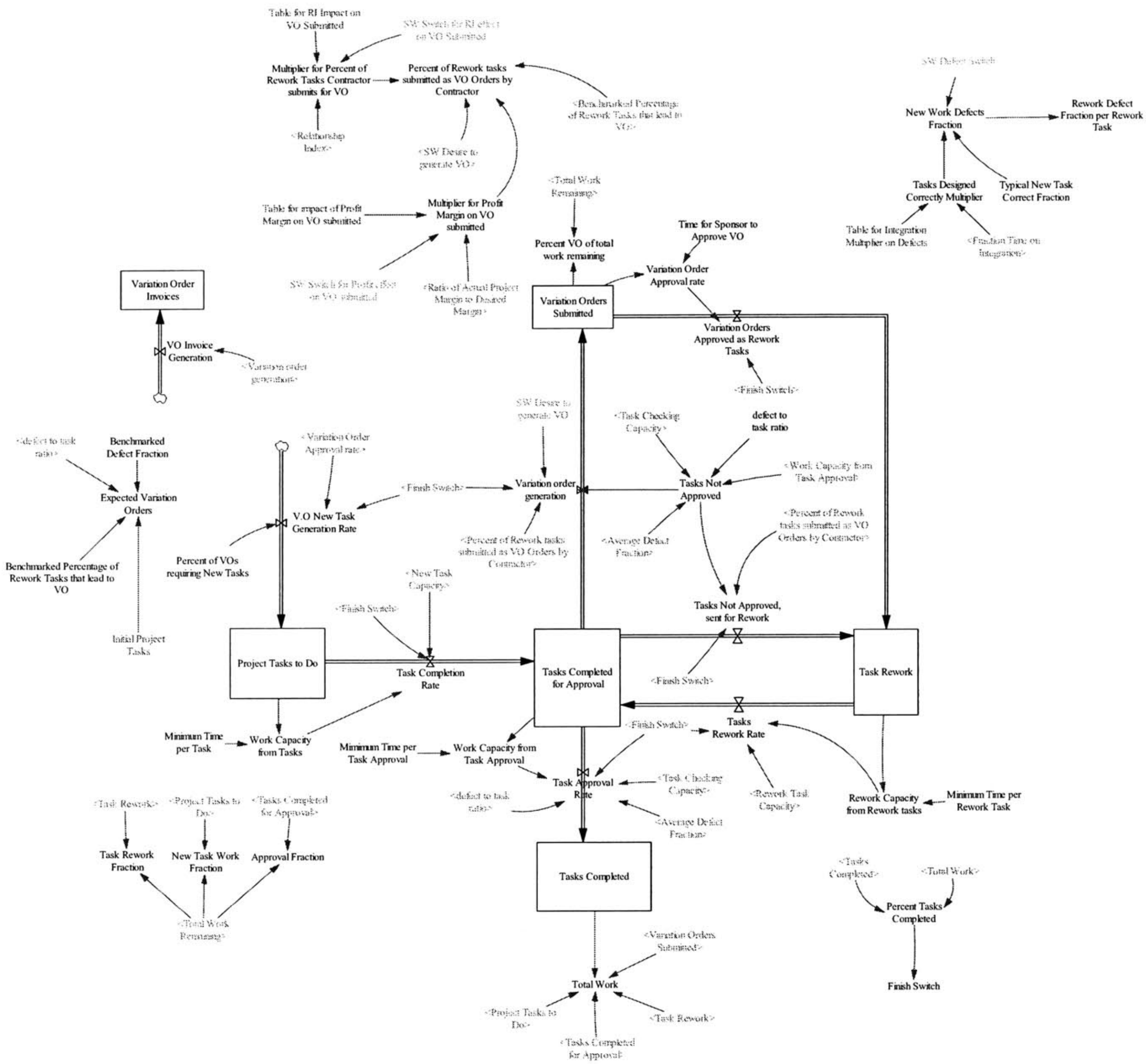

Figure 16. Thesis Model Work Cycle

6.2 Model Assumptions

The assumptions underlying the model structure are presented below:

Integration activities limit defects.

Defects or errors within the development of complex projects occur primarily as a result of designs having conflicting details, rather than as a result of calculation error. Engineers on the design teams of a project need to be informed of the way other elements of the design impact their work, and need to inform other design teams of their requirements and constraints. When teams fail to communicate, errors, design clashes and divergent designs emerge. This assumption underlies the linking of integration time and error rates in the model.

Management monitors the project schedule.

Contractor and sponsor management manages the project according to the schedule (in the model this is an initial condition of 100 weeks). The contractor will hire/allocate staff onto the project in response to schedule pressure. However, financial considerations also determine the contractor's response to schedule pressure. A contractor feeling financial pressure will not be as willing to shift staff onto the project or hire externally. Schedule pressure also impacts the amount of time staff will invest in integration activities. It is assumed that when staff feel under pressure to produce work they will cut back on the time they spend attending meetings and design reviews (integration activities) in a bid to work on "productive tasks".

Variation orders come first.

The contractors will devote time and resources to variation orders ahead of other project tasks. Variation orders represent an opportunity to generate additional income for the contractor, over and above the agreed contract. It follows that resources will be devoted to these activities as a priority.

Approval of variation orders takes time.

While generating variation orders are a priority for the contractors, the sponsor does not approve them instantaneously. Variation orders require time to be generated, documented and processed. The contents of the variation order become the subject of meetings to negotiate the cost, the extent of the change and to disseminate the changes to affected parties, seeking their response. Each variation order is tracked, audited and deliberated over by both the contractor and the project sponsor. This all takes time and during this time resources are devoted to the process by both parties.

Expectations exist for number of variation orders, time on integration and defect rates.

The project model is initialized with a number of benchmarked parameters. These include *Ideal Fraction Time on Integration*, *Benchmarked Percentage of Rework Tasks that lead to Variation Orders* and *Typical New Task Correct Fraction.* These initial conditions reflect the assumption that sponsors and contractors will enter a project with a track record of experience behind them. This experience leads them to have expectations of what a project will require in terms of time devoted to integration, how many variation orders they expect and what percentage of tasks will need to be reworked. These expectations then form both a comparative statistic for the actual project and a baseline from which the project deviates.

Working relationships determine time on integration and use of variation orders.

The strength of the relationship between the project sponsor and contractor determines, in part, the time devoted to integration activities. When the relationship between project teams deteriorates (whether in response to schedule pressure, or rising project costs through variation orders) the individuals in those teams are less willing to spend time with each other. Thus a poor relationship leads to decreasing time spent in integration activities. In addition, a poor relationship generates willingness to use variation orders. If the relationship has become adversarial between the sponsor and contractor then the contractor will feel justified in trying to "squeeze" the sponsor for more money.

No resource constraints.

The contractor is able to source as many engineers as are required, or desired, to staff the project. All engineers have the appropriate experience and skills needed to perform their work. In reality, contractors and project sponsors alike struggle to find the suitable human resources required. The appropriate skills are not readily available and all firms operate in a constrained market place. The scarcity of resources, and competition for same, drives sponsors to prematurely award contracts to ensure access needed skills and physical assets. Contractors are also at the mercy of this dynamic (even as they try to exploit it in negotiations with sponsors) and will sometimes find themselves without the needed skills to fulfill their contractual obligations. The industry will remain challenged by this scenario for years to come.

7.0 Analysis & Results

The results from the simulation of the project model are presented below. Section 7.1 examines the effect that the contract lump sum price has on the final cost borne by the contract sponsor. A number of different simulations were carried out with each simulation using the same underlying model and a range of pricing alternatives. The model was adjusted between simulations to capture the impact of various assumptions with respect to the contractor's behavior and thus project performance. For instance, the first simulation analyzed below included a number of assumptions that limited the impact of the agreed pricing on the contractor's hiring policies and use of variation orders. Section 7.2 will discuss the simulations in greater depth and explore the mechanisms driving the outcomes. Section 7.3 explores the sensitivity of these results to a number of key variables.

7.1 Effect of Agreed Lump Sum Price on Cost to Project Sponsor

7.1.1 Initial Conditions: Sponsor's Paradise

Project sponsors will attempt to maximize the value derived from a project by minimizing the lump sum cost of the contract agreed with the contractor. In the model the lump sum cost is based upon the agreed contracted engineering rate ("*Margin Accepted* *on Contract*") and the "*Estimated Staff Required*". The first simulation includes the following assumptions:

- That the agreed price will not affect the contractor's use of variation orders.
- That the price agreed will not impact the initial staff numbers the contractor assigns to the project.
- That the agreed price will not affect the desire/ability of the contractor to hire staff as needed during the project.

These assumptions are consistent with the project sponsor believing that the contractor will be required to execute the project under the contract terms (schedule and budget).

It should be noted that the "Project Sponsor Cost" indicated below does not include any costs associated with lost revenue from a delay in completing the project, for example lost oil production. It is exclusively the cost of the contract agreed with the contractor. This holds true for all the following analyses and any exceptions will be noted.

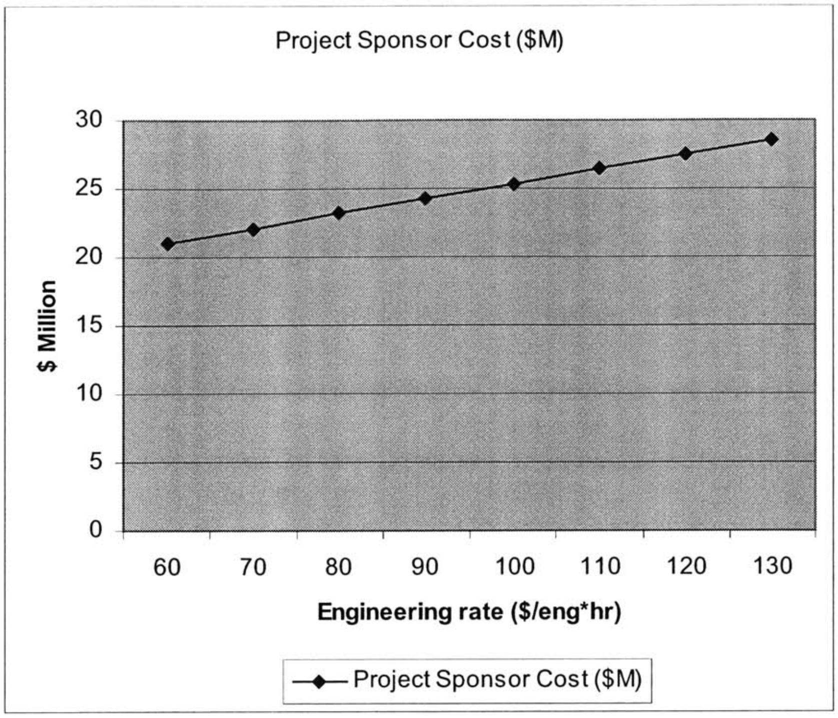

Figure 17. Project Sponsor Cost – No Profit Effects

With the assumptions listed above included in the model, the cost to the project sponsor is significantly reduced as a result of negotiating the cheaper engineering rate (total cost of $21.1 million versus $25.33 million at the "preferred" rate of $100/eng*hr. A saving of $4.23 million. Higher rates are shown for the purposes of comparison). To incorporate the assumptions in the model, the following changes were made:

- The variable "*SW Switch for profit effect on VO Submitted*" is set to 0.
- The variable "*SW Price impact on Initial Staff*" is set to 0.
- The variable "*SW Switch for Profit Multiplier on Hiring*" is set to 0.

Setting the switches to 0 effectively makes the contractor immune to pricing pressure with respect to initial staffing, hiring and the use of variation orders. It is not surprising therefore that under these assumptions a project sponsor is well served by driving the project price down.

7.1.2 Variation Orders are a Reality

The next simulation relaxes the assumption that the agreed price does not impact the contractors desire to use variation orders. Thus the variable "*SW Switch for Profit effect on VO submitted*" is set at 1. This leaves in place the following assumptions:

- That the price agreed will not impact the initial staff numbers the contractor assigns to the project.
- That the agreed price will not affect the desire/ability of the contractor to hire staff as needed during the project.

The relaxation of the variation order assumption is consistent with the views enunciated by a number of project managers interviewed. It is a widely held belief that the contracting community will use variation orders to secure revenue. It therefore makes sense to assume that the agreed price will affect the contractor's willingness to use available contract mechanisms to secure revenue. The results of the simulation are shown below. Again, the "Project Sponsor Cost" does not include revenue foregone from project delays.

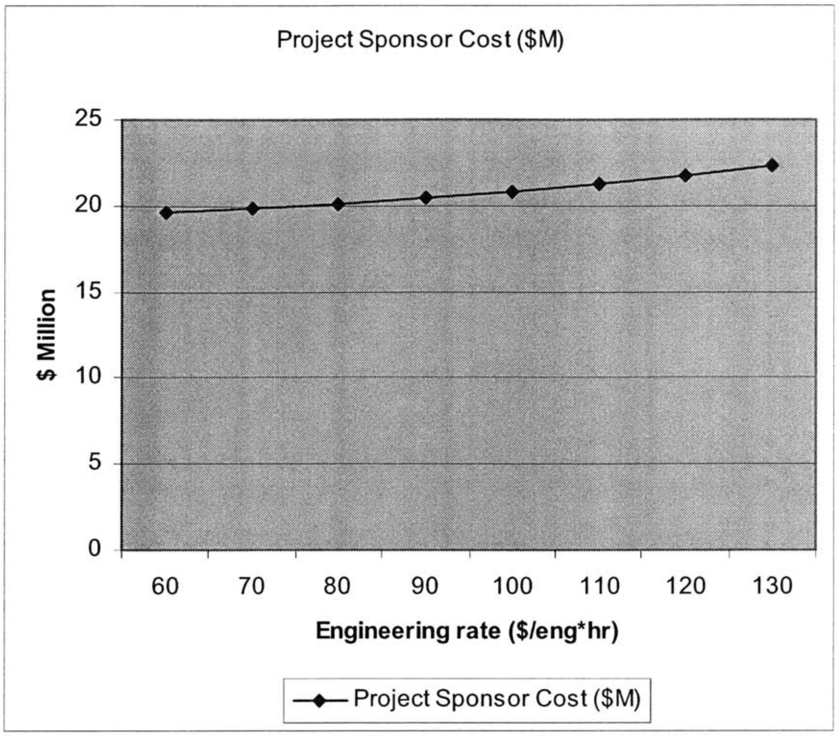

Figure 18. Project Sponsor Cost – Profit Effect on Variation Orders

As with the first simulation, the results above indicate that the project sponsor is best served by negotiating the lowest contract price possible. The benefit is not as marked ($19.63 million at $60/eng*hr versus $20.79 million at $100/eng*hr) with a "saving" of $1.16 million. The slope of the graph has been reduced. This is due to the increase in the costs associated with variation orders. As can be seen in Figure 19 the lower agreed price resulted in significantly more revenue being generated from variation orders than the contract executed at a higher agreed price. The difference of $3.15 million in variation order revenue (between a project using an agreed $60/eng*hr and one with an agreed rate of $100/eng*hr) is significant, but not enough to offset the savings created by selecting the cheaper option.

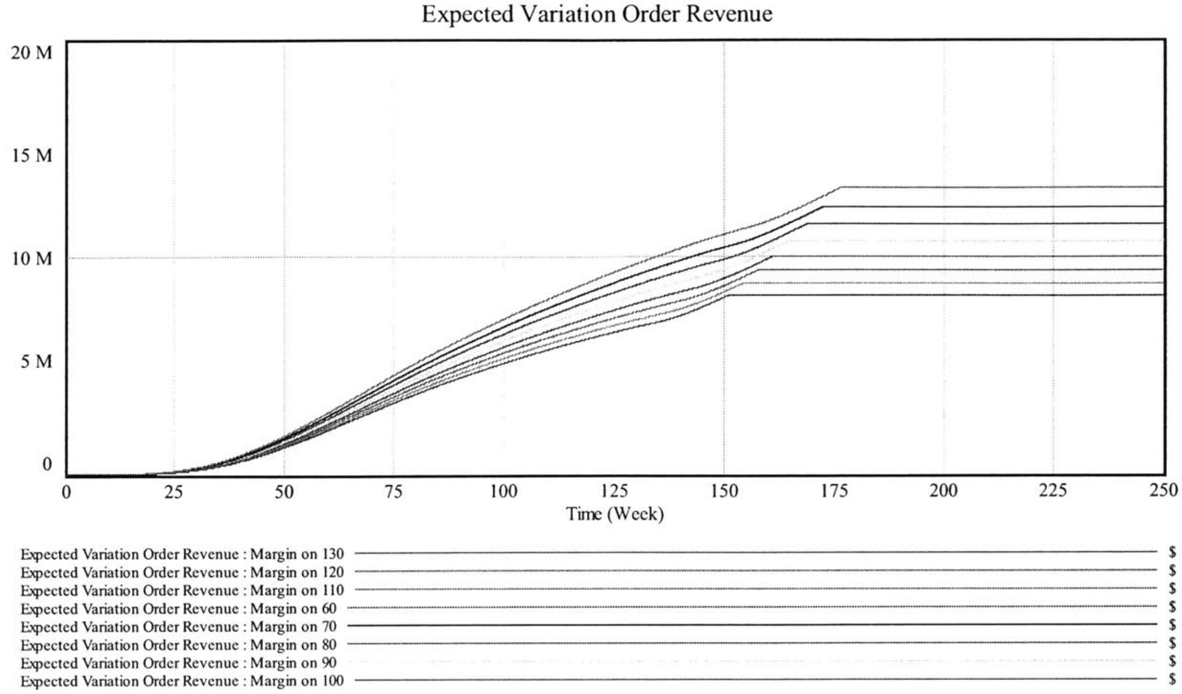

Figure 19. Pricing Effect on Variation Orders

7.1.3 A Smaller Team will get it Done.

The next simulation includes the effect of pricing on variation orders discussed above and also relaxes the assumption that the price will not impact the initial staffing level selected by the contractor. This is achieved by setting the variable "*SW Price impact on Initial Staff*" to 1. In effect this acknowledges that a contractor facing reduced margins on a project will attempt to complete the work with a smaller team. Project sponsors may well be aware of this. The final assumption is held in place:

- That the agreed price will not affect the desire/ability of the contractor to hire staff as needed during the project.

This combination of assumptions captures an environment in which the sponsor believes that the contractor is bound to execute the project and will still have to hire accordingly as the project progresses even if the initial team is a smaller "tiger team". The results of the simulation are shown below. Again, the "Project Sponsor Cost" does not include revenue foregone from project delays.

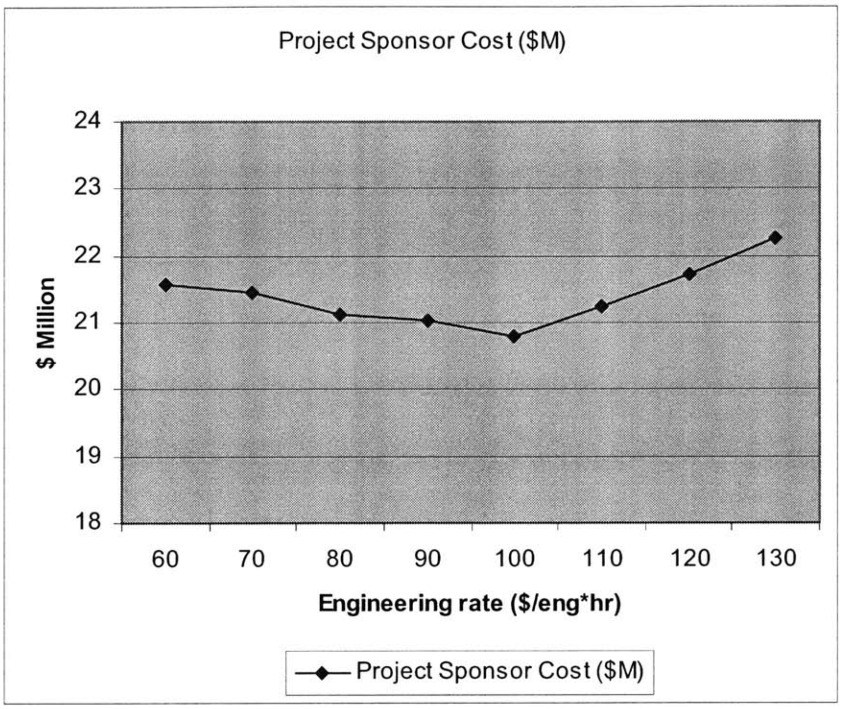

Figure 20. Project Sponsor Cost - Pricing Effect on Initial Staff

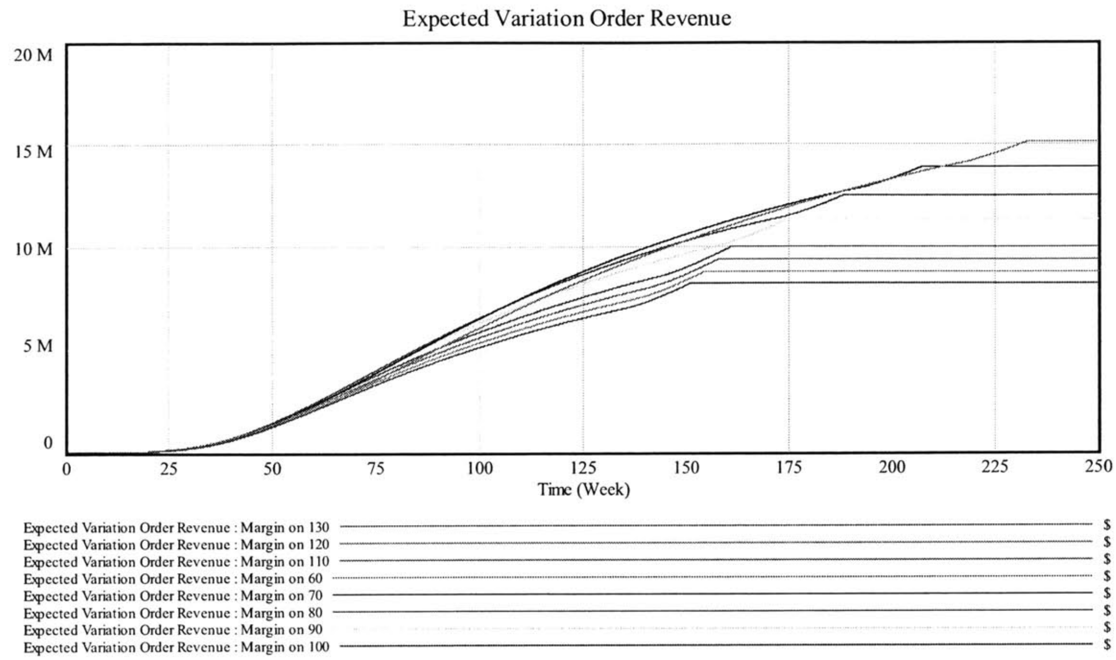

Figure 21. Variation Order Revenue with Pricing effect on Initial Staff

A number of interesting results appear from this simulation. First, the cheapest contract price no longer results in the lowest cost to the project sponsor. Negotiating for an engineering rate of $60/eng*hr results in a total payment to the contractor over the project of $21.57million. Accepting $100/eng*hr results in a total payment of $20.79 million. Thus the “cheaper” contract ends up costing $780,000 more. Second, the delays to the project are becoming significant. The project finishes in week 161 (61 weeks beyond the planned completion date of 100 weeks[29] - the point at which the plot becomes a flat line indicates project completion) for the agreed price of $100/eng*hr. For the cheaper

[29] As discussed in Section 6 the model is initialized with a target completion date of 100 weeks. This is used to calculate the initial staff required by the contractor to execute the project. As in reality, this calculation does not accurately predict the amount of re-work required during project, nor the full extent of variation orders submitted. As a result the project schedule slips relative to the predicted completion date even for “ideal” contract rates. This is acceptable in a simplified model such as the one developed for this thesis as it is more important to see the relative performance of the project under different assumptions than the absolute numbers. Of course, it also reflects the reality of most projects quite nicely as well!

contract the project is completed in 232 weeks. This brings with it substantial costs to the project sponsor above those of the payments to the contractor.

7.1.4 People Cost Money

The final simulation relaxes the last assumption; namely that the price agreed for the contract does not affect the contractor's ability or desire to staff the project. This is achieved by setting the variable *"SW Switch for Profit Multiplier on Hiring"* is set to 1. The effect of this is to enable the contractors to consider the profitability of the project in making hiring decisions. Lower profitability translates into the contractor being reluctant to hire engineers for the project.

With this last assumption lifted the contractor now considers project profit in decisions related to the use of variation orders, the initial staffing of the project and the on-going hiring of staff for that project. The results of the model simulations are shown below.

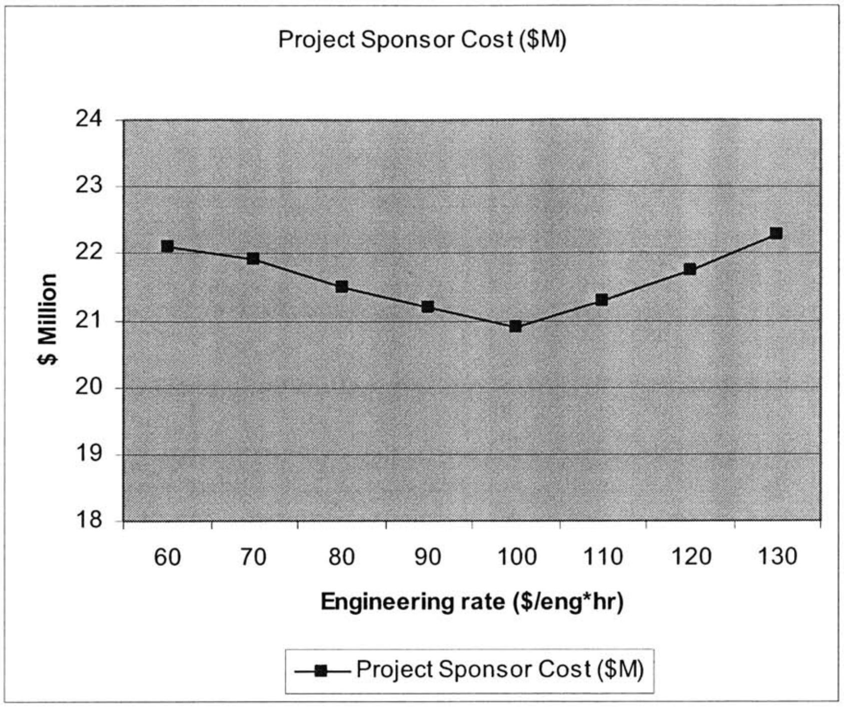

Figure 22. Project Sponsor Cost – Pricing Effect on On-going Hiring

It can be seen that under these conditions, the lowest priced contract results in project costs significantly higher than those accrued at the preferred higher contract price. The project ends up costing $22.09 million at $60/eng*hr, some $1.21 million more than the $20.88 million price tag at $100/eng*hr. The impact of the revised model is also evident in the variation order revenues (see below), with $15.62 million in expected variation order revenues for the cheaper contract as compared with $10.09 million at $100/eng*hr and $8.25 million at $130/eng*hr.

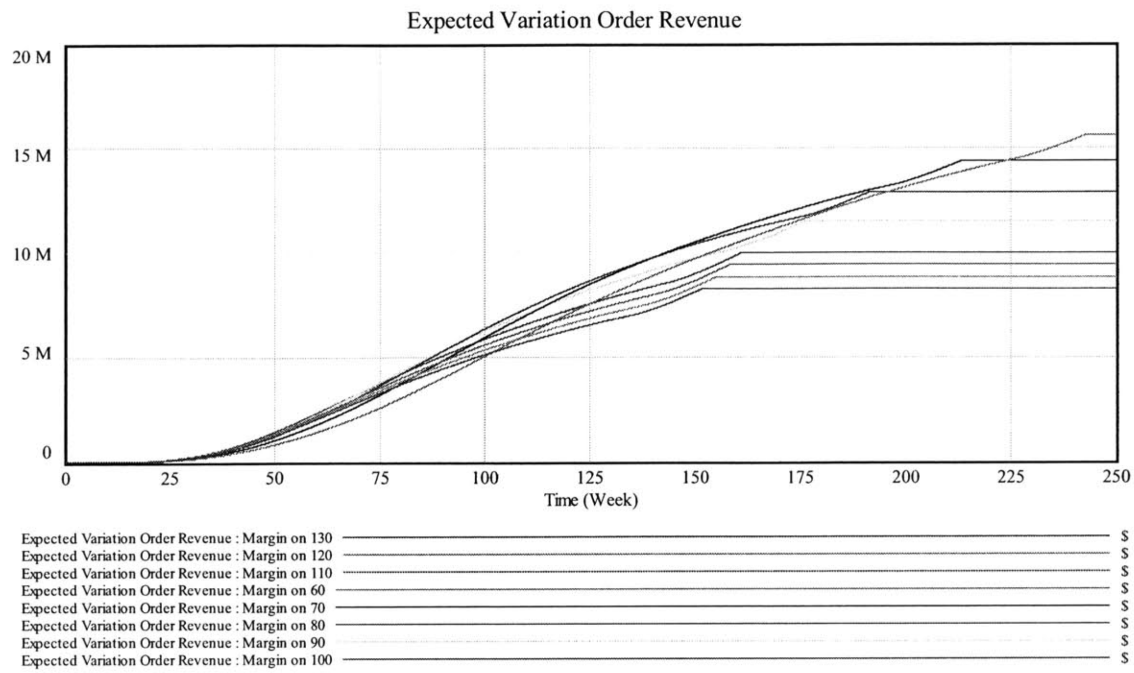

Figure 23. Variation Order Revenue – Pricing Effect on On-going Hiring

The project also suffers from substantial delay. The cheaper contract is now competed in week 243. If we include the sponsor's financial penalty associated with the delay (lost oil production for example), then the project sponsor cost results appear even worse. Figure 24 includes the impact of the project delay in the cost calculations.[30] It can be seen that when calculations include the costs of the project delay that these quickly dwarf the "savings" to be made from selecting the cheapest contract price.

[30] The delay cost is based on the project delivering revenue to payoff development cost in approximately 70 weeks. i.e the expected revenue stream from the project is $200,000 a week. Each weeks delay on project delivery "costs" the project sponsor $200,000 in foregone revenue.

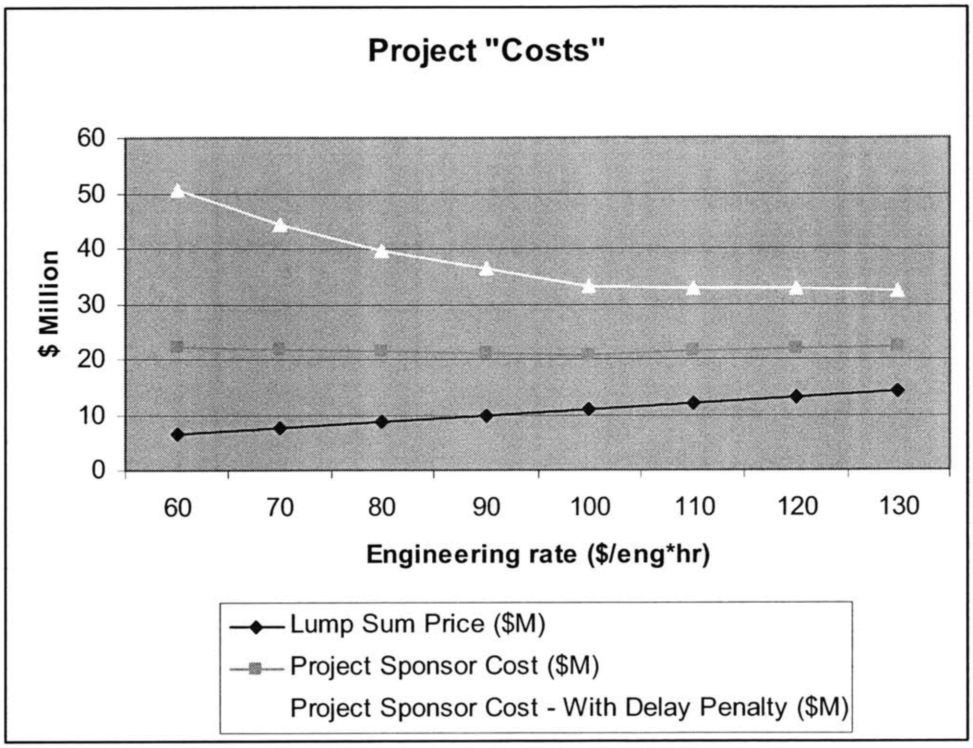

Figure 24. Cost of Project: Lump Sum, Total Cost and Lost Earnings Included

7.2 Analysis of Results

It is important to understand the factors that lead to the results described above. The first substantive change in the results (i.e reversing the slope of the plot of costs as a function of price) occurred when the initial staff calculations included a pricing effect. The analysis will begin with this before considering the case of no restrictions.

7.2.1 A Smaller Team Costs More

With the pricing impact on initial staff constraint removed, a lower agreed price provides an incentive for the contractors to reduce the staff they allocate to the project. Under the restrictive assumption (section 7.1.2) 27 engineers were initially allocated to the project. With freedom to set the initial staff numbers the project staff drops to 16 at $60/eng*hr. As the project progresses the smaller staff does not deliver the progress anticipated by the project schedule. The result is increased schedule pressure (see below). The plots are of two projects, both at $60/eng*hr, but with one the "unaffected" version having no impact on initial staff numbers from the reduced project price.

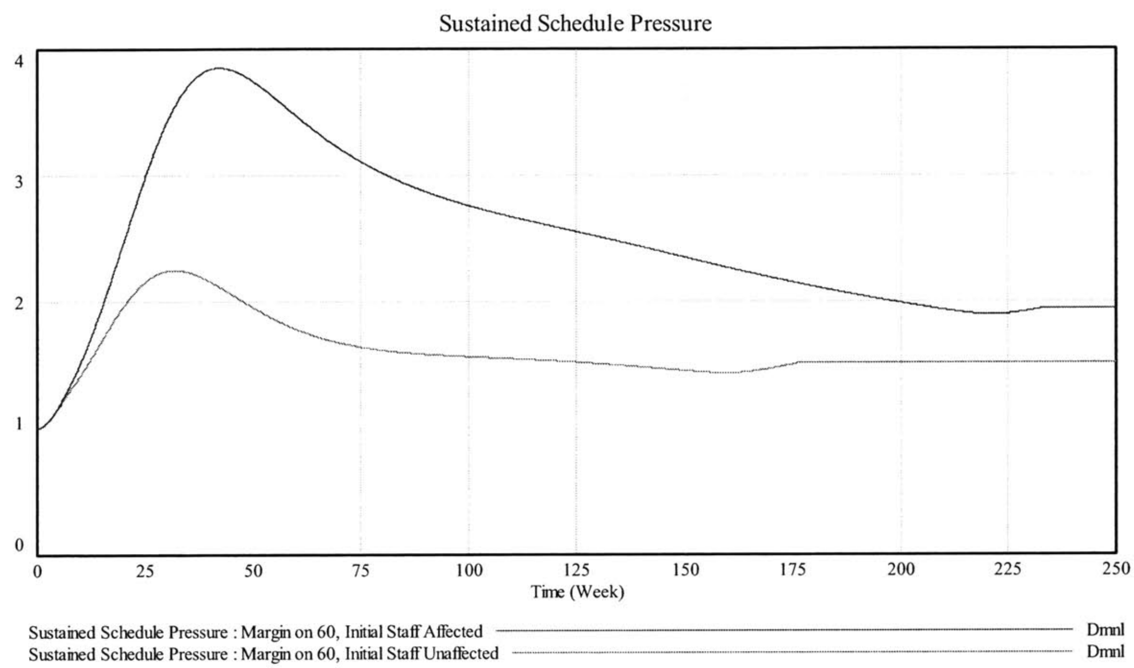

Figure 25. Sustained Schedule Pressure – Reduced Initial Staff

This schedule pressure translates into a reduction in the amount of time invested in integration activities[31] (see Figure 26). This leads to an increased defect rate as less communication results in suboptimal design.

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[31] As schedule pressure mounts the engineers focus on the "task at hand". Attending integration meetings etc receives less attention as the need to get the drawings "out the door" dominates. Under these conditions it is inevitable that effort is directed away from integration activities and towards completing detail design work.

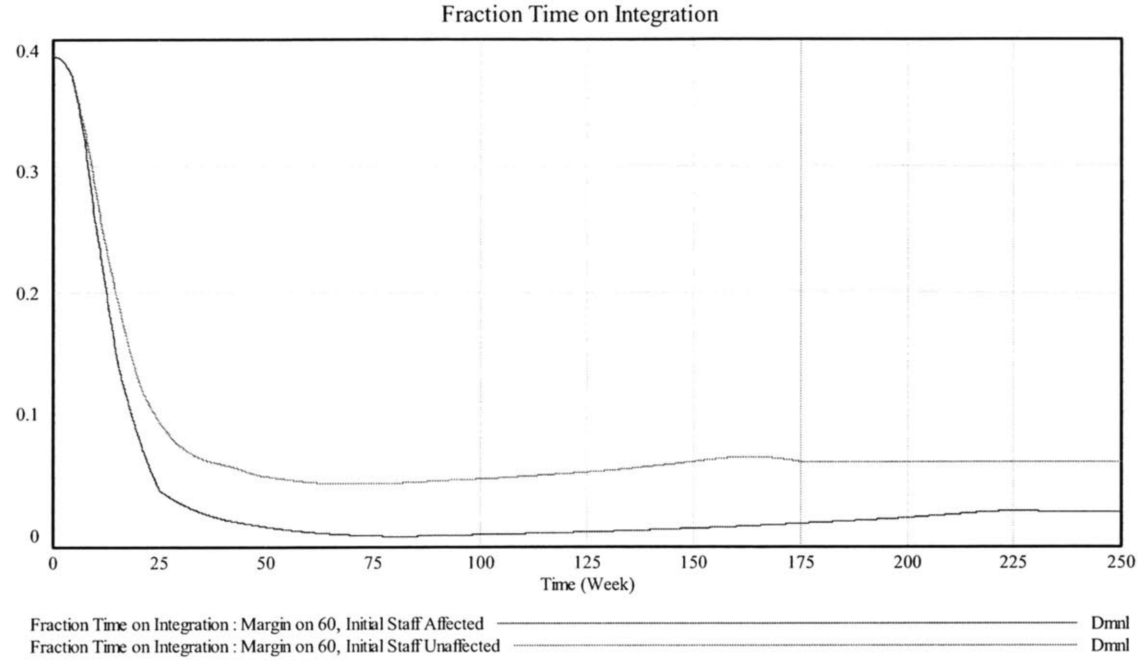

Figure 26. Fraction Time on Integration – Reduced Initial Staff

In addition the schedule pressure increase stimulates hiring of staff by the contractor to meet the project demands. Schedule pressure and increased staff numbers combine together producing an adverse effect on the relationship between the sponsor and contractor. This also limits the investment the firms make in integration activities. The result of higher defect rates, and a weakened working relationship is more rework and more variation orders (see Figure 27 and Figure 28).

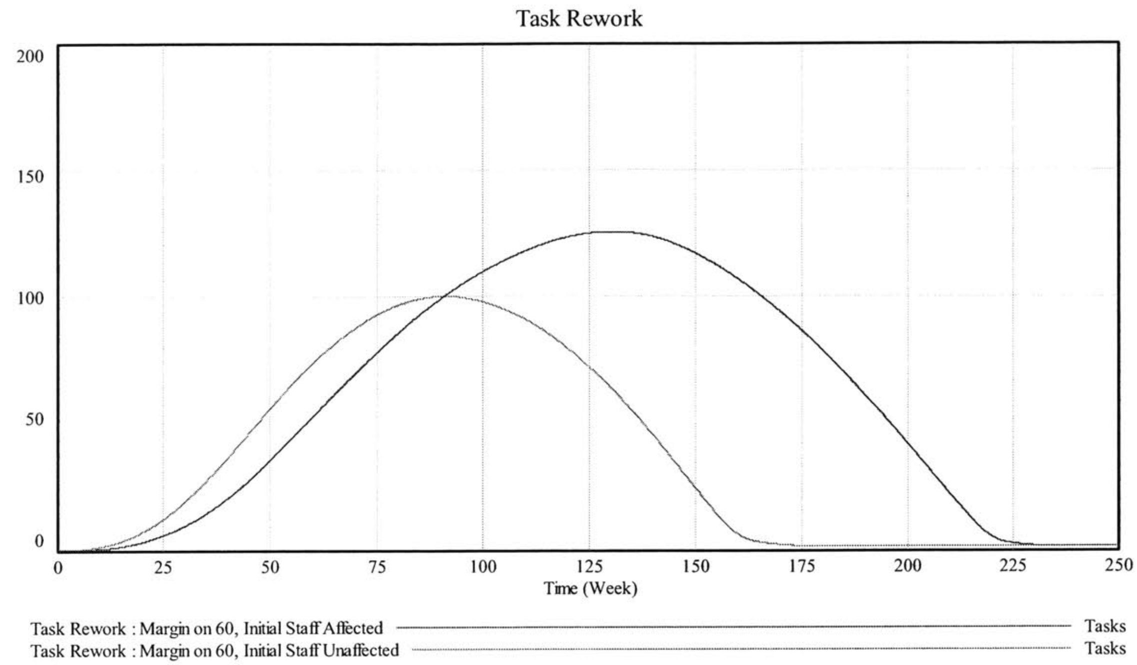

Figure 27. Task Rework – Reduced Initial Staff

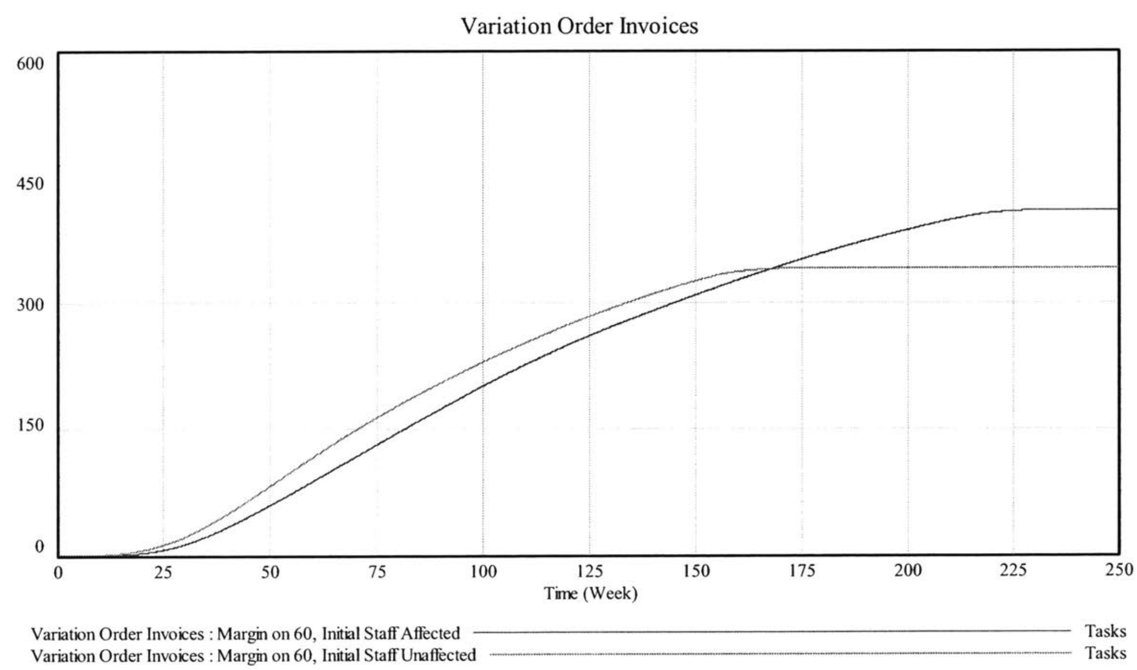

Figure 28. Variation Order Revenue – Reduced Initial Staff

Thus the relaxation of the assumption that a lower priced project will not impact the initial staff numbers leads to quite significant project cost increases for the "cheaper" contracts. The dynamics explored above also account for the cost difference between the project priced at $60/eng*hr and one at $100/eng*hr. This is because the more expensive project uses an initial staff of 27 engineers and thus begins with the same staff numbers (27 engineers) as the scenario where the price impact on initial staff is restricted.

7.2.2 People Cost Money, but not as much as Not Having Them

The final set of simulations presented in section 7.1.4 removed all the restrictions related to the effects of project profit on contractor behavior. The contractor therefore considered the project's profitability when making decisions regarding hiring in addition to variation orders and establishing the initial staff size. The decision process is captured in the model by the *"Total Staff Multiplier"* variable. This variable is multiplied by the *"Initial Full Time Staff"* variable to calculate the *"Indicated Desired Full Time Staff"*. The impact of profit (or lack thereof) can be seen below in the plot of *"Total Staff Multiplier"*. To demonstrate the impact of the profit assumption two simulations were run: "Affected" and "Unaffected". The "Affected" included profit margin affects on staff hiring, the "Unaffected" run did not. Both were run at the agreed contract rate of $60/eng*hr. As can be seen below the *"Total Staff Multiplier"* for the "Affected" simulation lags the "Unaffected" simulation.

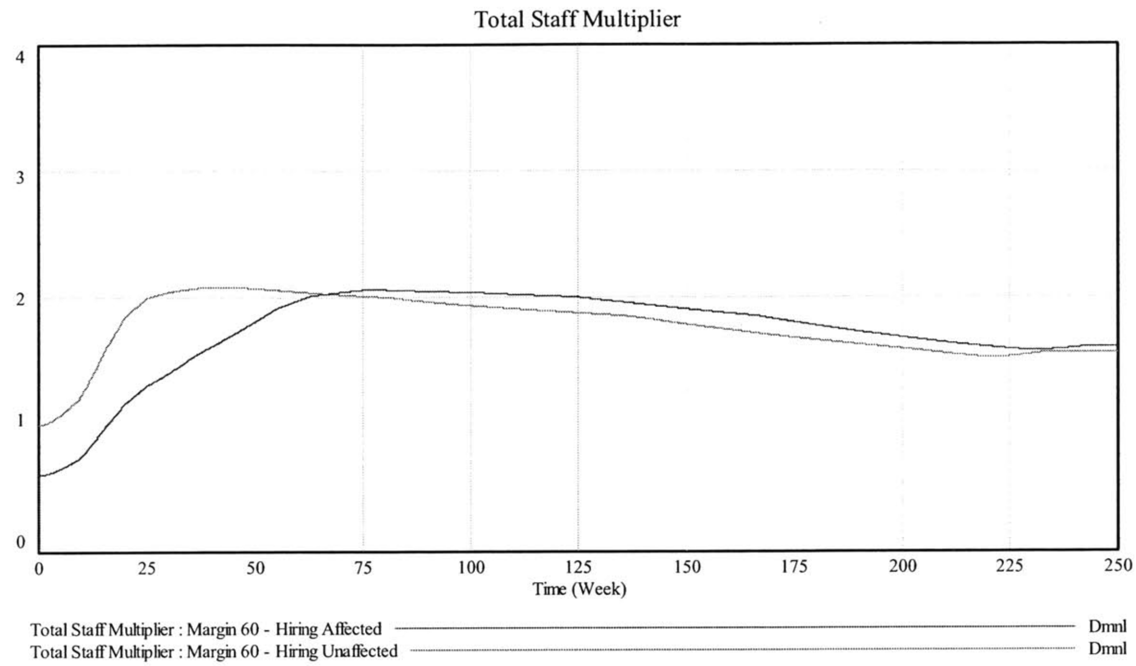

Figure 29. Total Staff Multiplier – Hiring Affected

What element of a real contractor's behavior does this plot describe? Simply that the contractor, experiencing disappointing financial returns for the project, does not want to carry the costs of higher staff numbers. Consequently the contractor does not man up as rapidly in response to the schedule pressure, leading to lower work rates and even higher schedule pressure (see Figure 31).

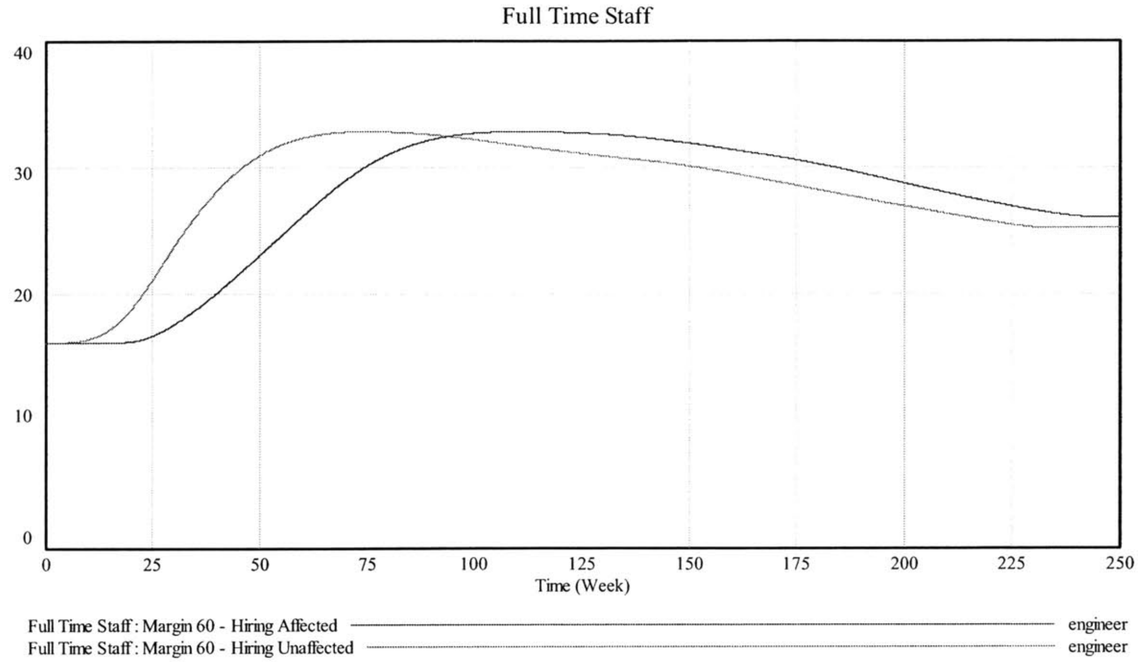

Figure 30. Full Time Staff – Hiring Affected

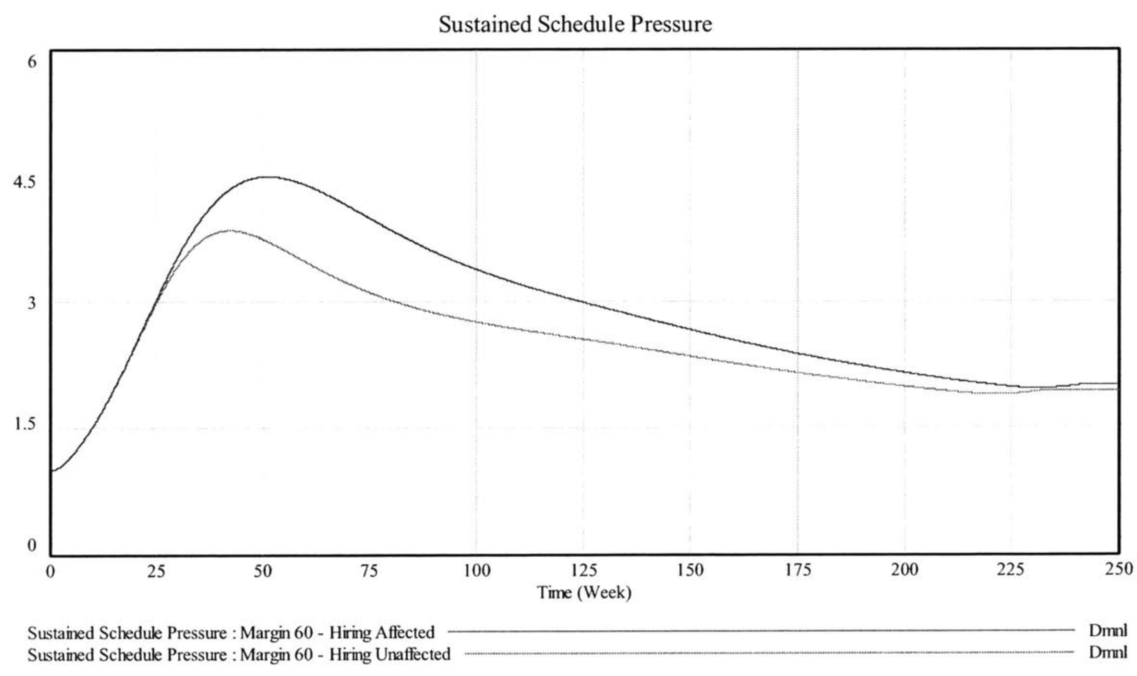

Figure 31. Sustained Schedule Pressure – Hiring Affected

The excess schedule pressure resulting from the revised hiring practice worsens the relationship between contractor and sponsor. As seen previously, schedule pressure and a poor relationship both negatively impact the time contractors devote to integration activities. The result of curtailed integration time is of course more defects and thus more variation orders (particularly if the relationship is under heightened strain). This is evidenced in the plot of *"Variation Orders Submitted"* shown below.

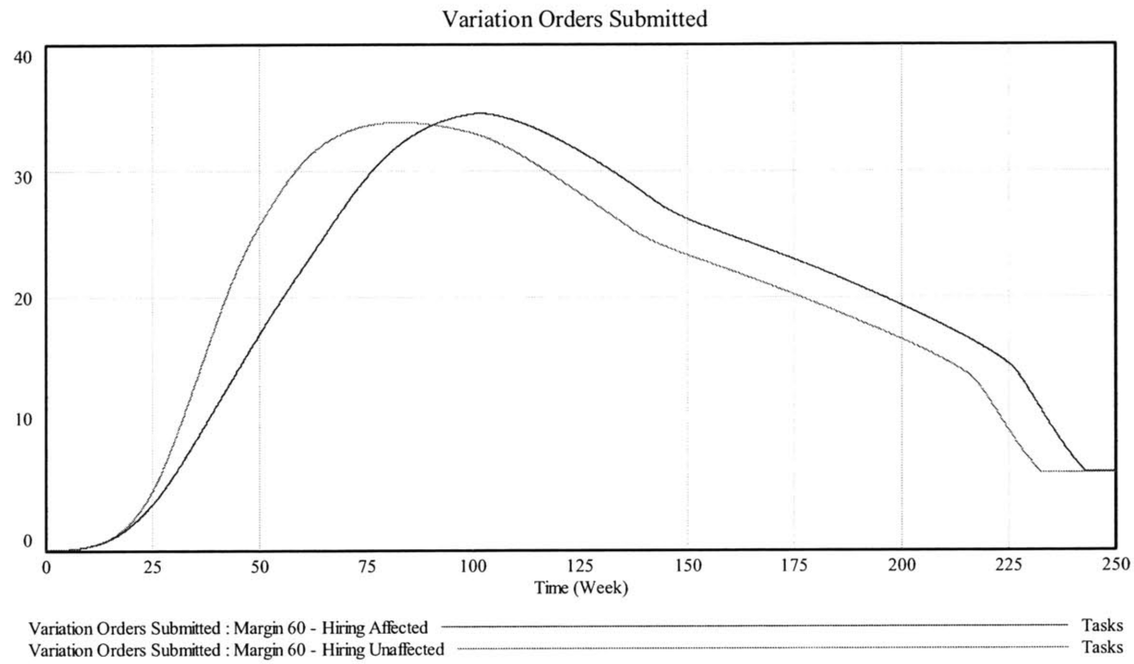

Figure 32. Variation Orders Submitted – Hiring Affected

The upshot of profit pressure on hiring are the results presented in section 7.1.4: the cost of the project creeps up further and the schedule delay continues to extend.

The above analysis discussed the effect of contractor's profit on hiring by comparing two simulations: one which included the effect and one which did not. We now need to explore how different project pricing levels, when combined with the profit effect on hiring, shape the outcome of the project. To keep the plots simple two simulations will be compared; one at $60/eng*hr and one at $100/eng*hr.

As discussed previously, the cheaper contract commences with fewer staff than the more expensive contract (16 rather than 27). The smaller project team does not deliver the work completion rate anticipated by the schedule and the result is increased schedule pressure. This creates a need for additional staff which the price restricted contract is unable to respond to as effectively as the more expensive contract. As can be seen in the plot shown below the expensive contract begins with more staff and responds to schedule pressure by hiring as required. The cheaper contract has a damped response, however the sustained schedule pressure (shown in Figure 34), has the ultimate effect of forcing the cheaper contract to more than double it's initial staff to 33 full time staff.

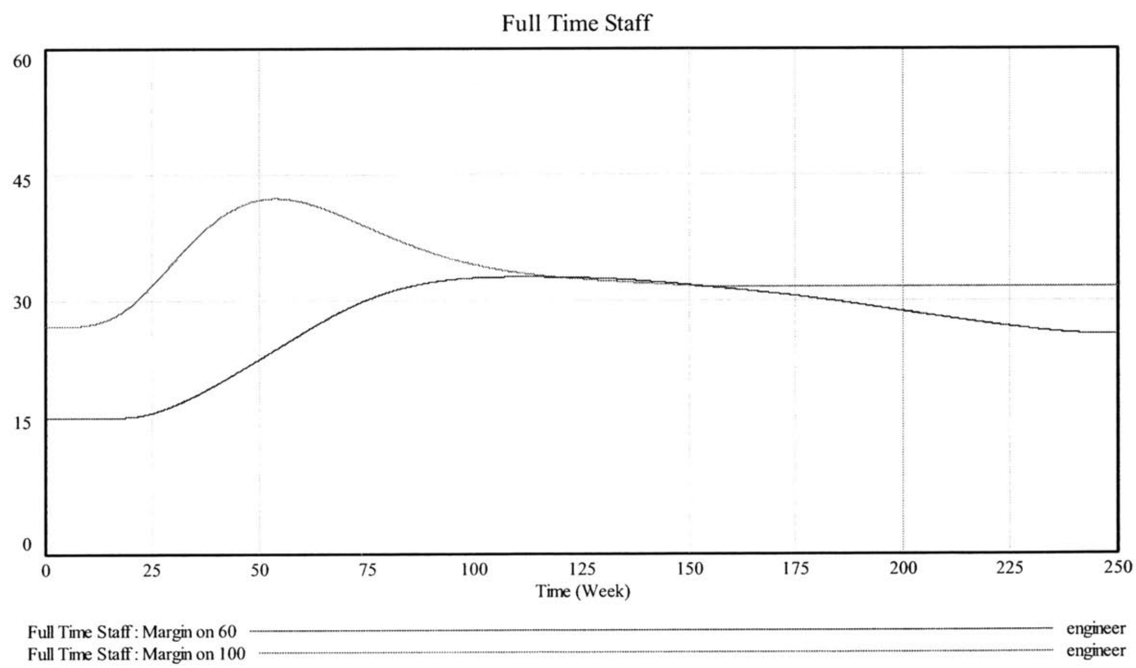

Figure 33. Full Time Staff – Profit Margin Effect Included

Schedule pressure remains more acute for longer at $60/eng*hr than $100/eng*hr.

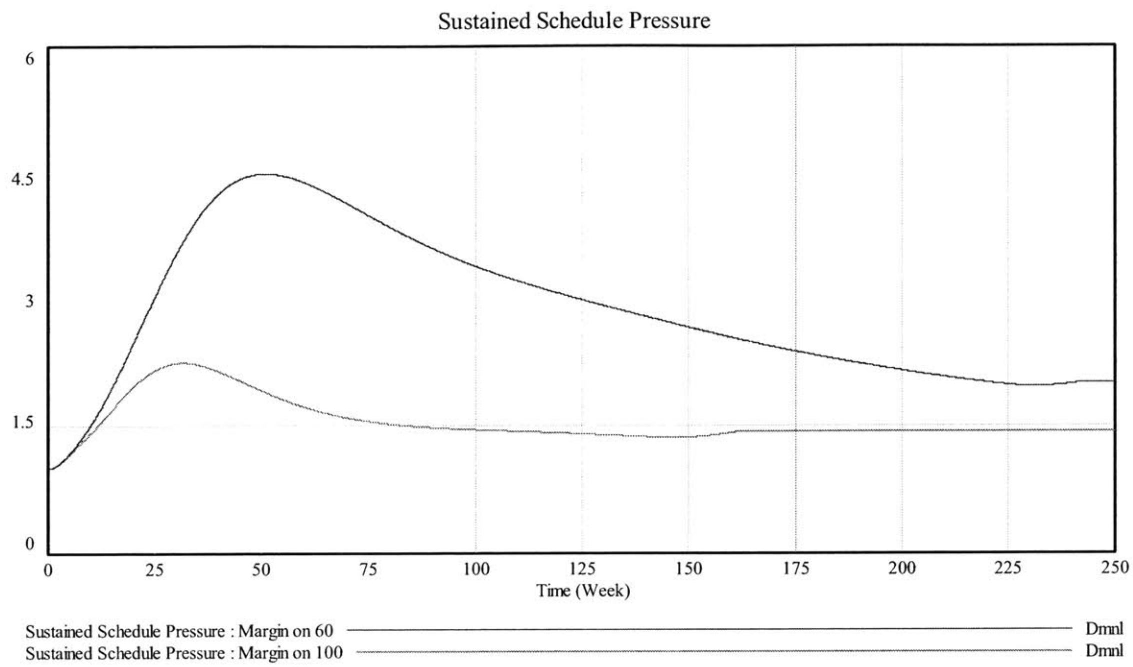

Figure 34. Sustained Schedule Pressure – Profit Margin Effect Included

Schedule pressure adversely affects the amount of time devoted to integration activities and as a result defect rates increase and rework is generated. It is therefore not surprising that the $60/eng*hr contract project experiences more rework than the $100/eng*hr project.

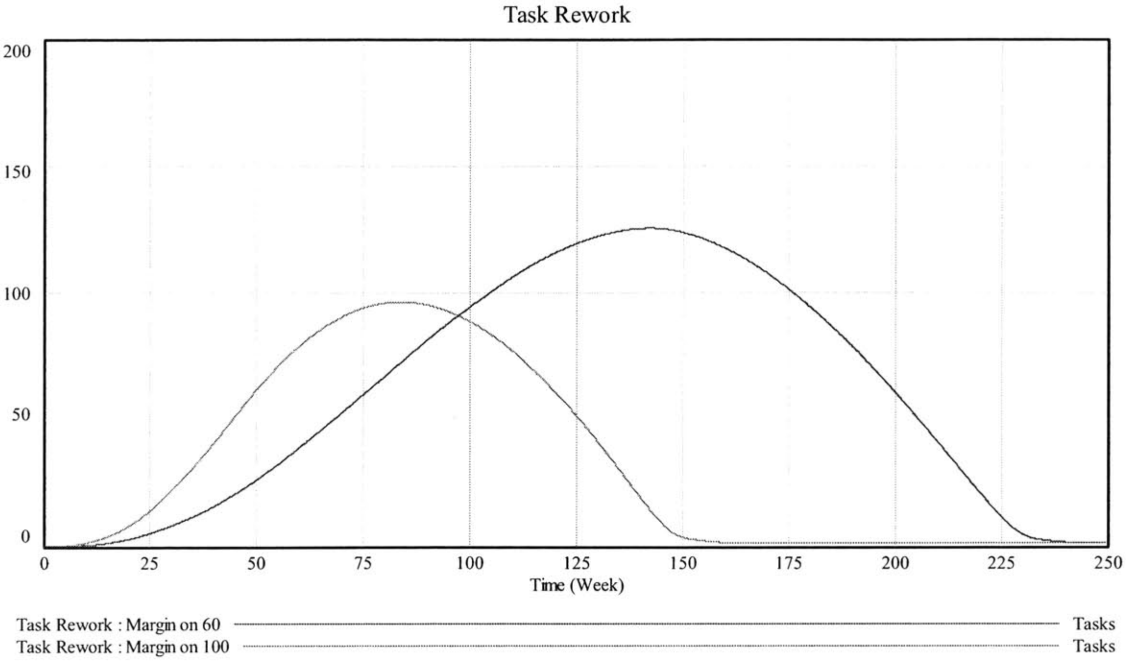

Figure 35. Task Rework – Profit Margin Effect Included

Rework represents additional tasks over and above the original schedule adding to the schedule pressure and requiring additional resources. As we have seen before schedule pressure damages the relationship between the project sponsor and the contractor as does an increase in initial staff numbers. Deteriorating relationships, combined with financial pressure leads to increased use of variation orders (and given that variation orders are generated from rework task it also holds that increased rework, ceteris paribus, would result in increased variation orders). We therefore expect that the cheaper contract generates more variation orders than the more expensive contract. And so it proves to be (see below).

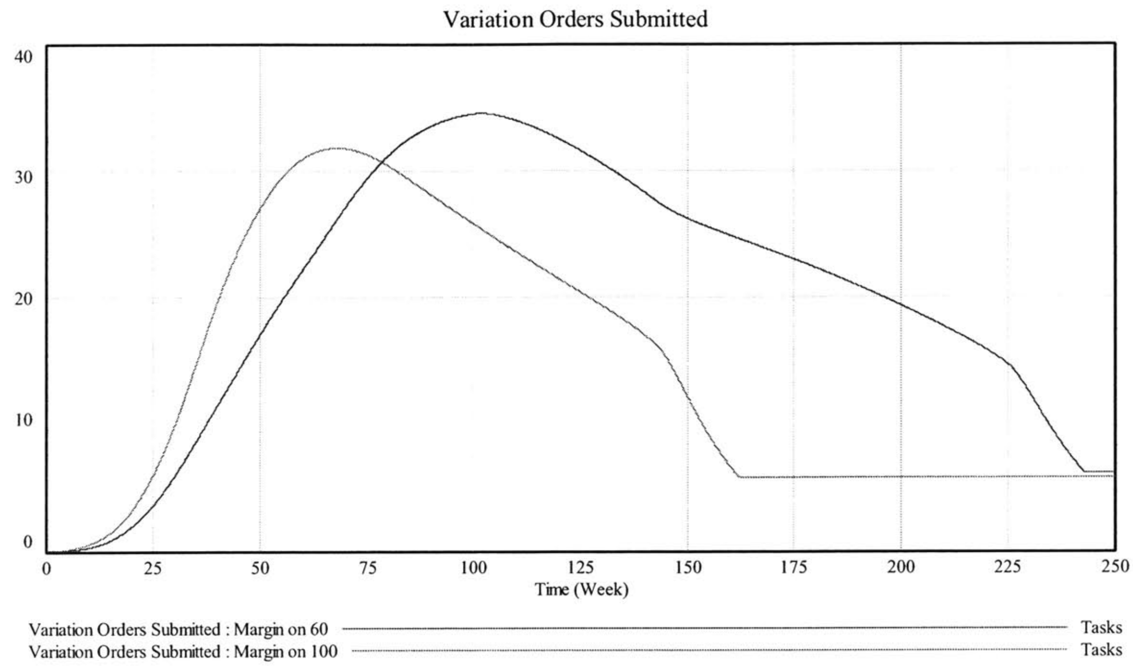

Figure 36. Variation Orders Submitted – Profit margin Effect Included

The end result is that the “cheaper” contract ends up being the more expensive one.

7.3 Sensitivity Analysis

The results presented above strongly suggest that cheaper contracts can result in more expensive projects once the full implications of resourcing restrictions and revenue seeking incentives are included. However, it is important to understand how sensitive the model is to changes in key parameters. Could small changes in an assumed variable value significantly alter the results presented?

Vensim™ provides a number of tools to help answer that question. A first step is to utilize the optimization feature. This allows for the effect of varying the predefined constants to be evaluated with respect to a payoff function (a single variable that captures the important features of the model in a single number – *"Project Sponsor Cost"* in this case). A number of these optimizations were conducted with the model constants being varied by +/- 50%. A range of payoff functions were used, including *"Project Sponsor Cost", "Expected Variation Order Revenue"* and *"Variation Orders Submitted"*. The output of these optimization runs (See Appendix C) lists the constants, in descending order, of most impact on the payoff function.

The output revealed a number of influential parameters. Of interest were those that made a difference when the issue of contract price was considered. Putting it another way, constants such as the *"Initial Project Tasks",* while revealed as important, are important notwithstanding the contract price. By controlling for the constants that most impact variation orders the following three variables were found to be of particular interest: *"Variation Order Mark Up", "Time for Sponsor to Approve VO"* and *"Ideal Fraction Time on Integration"*.

7.3.1 Sensitivity to Variation Order Mark Up

The rate at which a contractor charges for variation orders does not have to be the same as the rate accepted for the general contract. The *"Variation Order Mark Up"* variable accounts for this. A number of simulations were run with different contract prices and different mark up multipliers. The results can be seen in Figure 37 below. As expected a higher mark up percentage increases the costs for the project sponsor. However, it is interesting to note that the variance of costs associated with the initially cheaper contract is higher. The $60/eng*hr contract has an average cost of $20 million with a variance of $1.2 million, compared with an average price of $19.6 million and a variance of $0.44 million for a contract at $100/eng*hr.

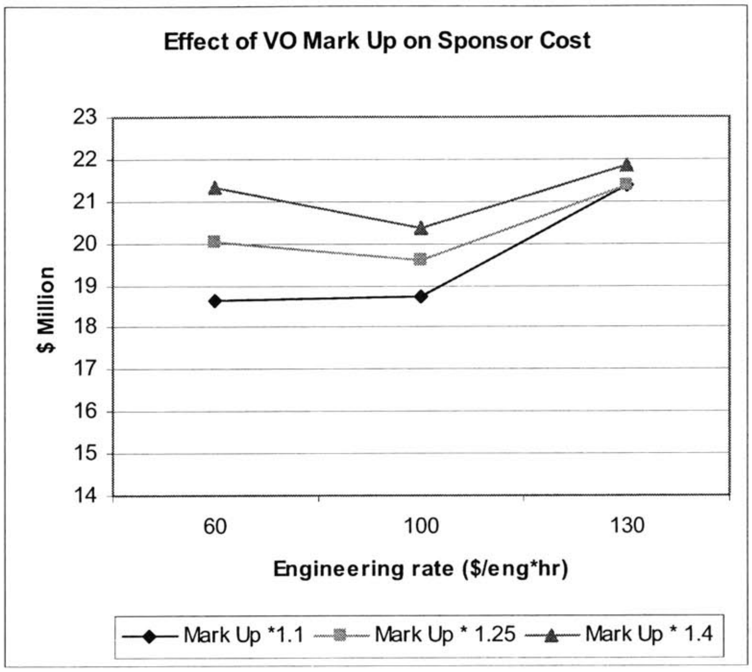

Figure 37. Project Sponsor Cost – Effect of VO Markup

Agreed Contract Rate ($/eng*hr)	Mark Up % 110	Mark Up % 125	Mark Up % 140	Average	Variance
60	18.63	20.05	21.31	20	1.20
100	18.76	19.59	20.38	19.58	0.43
130	21.38	21.38	21.83	21.53	0.045

Table 2. Project Sponsor Cost ($M) – VO Markup Varied

From a sponsors point of view this suggests two things. First, that to control for the variance of outcomes a higher initial project price may be warranted. Secondly, that it is important to be aware of the contractors anticipated mark up for variation orders. Of course, the lower mark up percentage also delivered additional project delays as shown in the figure below. The cost of any delay may offset the advantage to be gained by pushing for lower mark up rates.

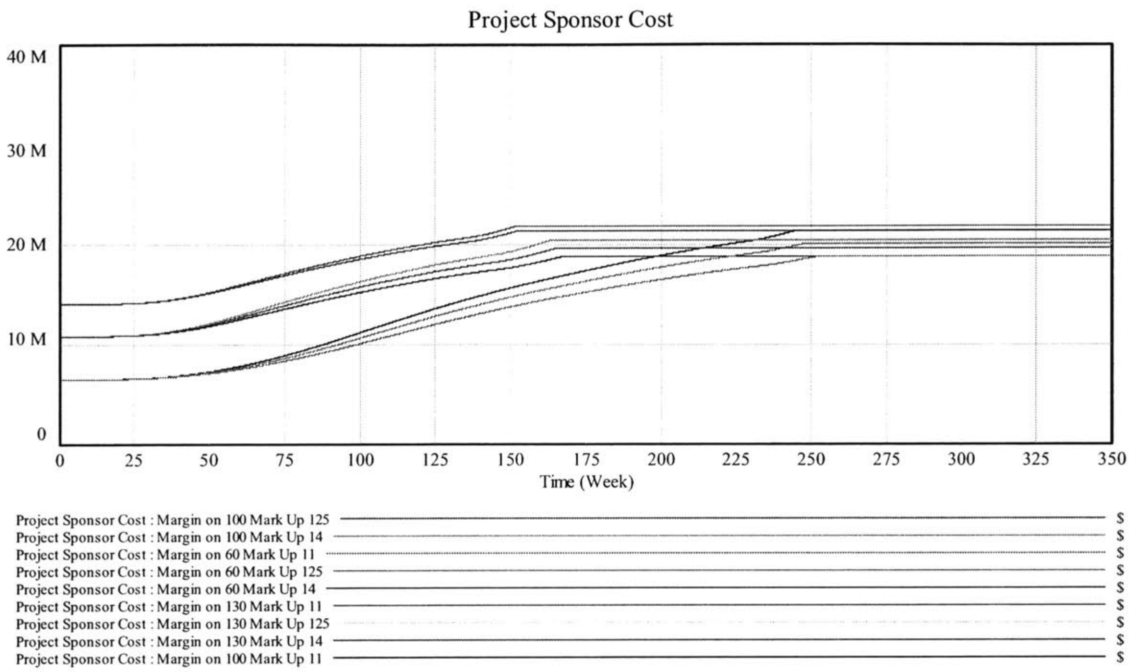

Figure 38. Effect of VO Markup – Contract Margin Varied

7.3.2 Sensitivity to Variation Order Approval Time

Once variation orders are generated considerable work ensues with respect to negotiating the variation and approving the changes (and particularly the cost of those changes). This approval process can take considerable time, and to a large extent is controlled by the project sponsor. Thus it was important to consider the sensitivity of the overall project cost to variations in the approval time, not only from the perspective of cost outcomes, but also as this may offer the sponsors an opportunity to influence project outcomes. The results are particularly interesting (see Figure 39 below).

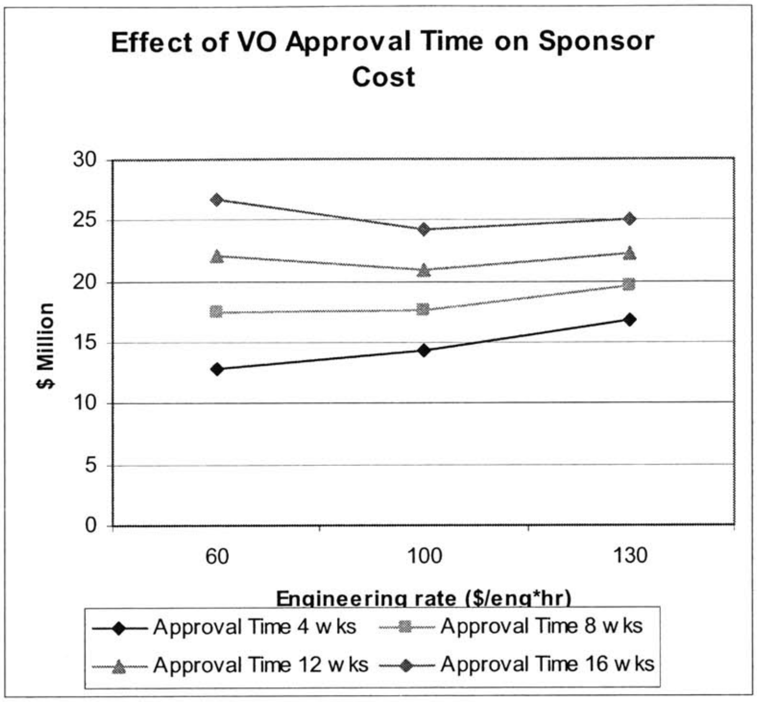

Figure 39. Project Sponsor Cost – VO Approval Time Varied

It can be seen that the variation order approval time has significant influence on the overall project cost. Changing the approval time from 16 weeks to 4 weeks results in savings of nearly $14 million at a contract rate of $60/eng*hr! (See Table 3 below). Why does this occur?

Agreed Contract Rate ($/eng*hr)	Approval Time 4wks	Approval Time 8wks	Approval Time 12wks	Approval Time 16wks	Average	Variance
60	12.79	17.53	22.09	26.77	19.8	27.03
100	14.29	17.59	20.88	24.19	19.24	13.60
130	16.85	19.58	22.27	25	20.93	9.20

Table 3. Project Sponsor Cost ($M) – VO Approval Time Varied

Once a variation order is approved it becomes either a rework task, or a new task (if inadvertently left out of the initial contract). Approval lets the work move forward. Delaying the approval delays completion of the work, and diverts the contractors resources towards the inevitable meetings associated with obtaining approval. In addition, delayed approval is likely to have adverse effects on the relationship between the contractor and sponsor (as the contractor becomes frustrated that no agreement on the changes are reached, and the sponsor becomes irritated at the contractor raising the issue at each meeting - even those meetings not directly related to the changes) generating more delays and variation orders.

Again it is interesting to note that while all agreed contract prices benefit from faster variation approval, the cheaper contracts are affected more strongly. The variance of the project cost at $60/eng*hr is $27 million compared with $13.6 million at $100/eng*hr. Cheaper contracts again prove to be more volatile.

7.3.3 Sensitivity to Ideal Fraction Time on Integration

The final set of sensitivity analysis presented considers the effects of varying the assumed ideal fraction of time devoted to integration activities. The variable *"Ideal Fraction Time on Integration"* is set to 0.4 in the model. This suggests that under ideal conditions the contractor would devote 40% of their time to engaging in the critical integration activities required for executing complex projects. In some respects this could be considered a proxy variable for the perceived complexity (or integrality) of the system. More complex systems will require devoting more time to integration tasks. A number of interesting results become apparent when the *"Ideal Fraction Time on Integration"* is varied.

First, it is again clear that a cheaper contract price is accompanied by increased variance of outcome, as a function of ideal integration time (see Figure 40 below). A contract struck at $60/eng*hr has a variance of $0.59 million, compared with $0.043 million for a contract set at $100/eng*hr. This follows the pattern seen in each of the above sensitivity analysis. Cheaper contracts appear more volatile with respect to a number of parameters.

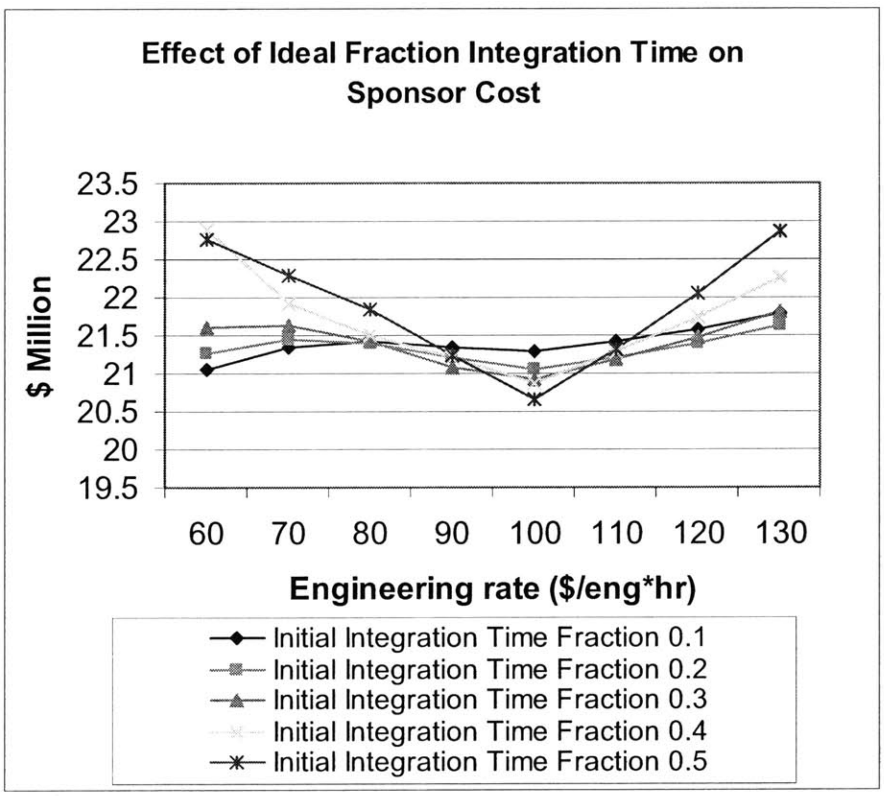

Figure 40. Effect of Varying the Ideal Fraction Integration Time

A second interesting result emerges from this sensitivity analysis. If we calculate the variance of the project cost as a function of the ideal time devoted to integration activities, we see that the "simpler" projects (assuming ideal integration time to be a proxy for project complexity) have lower cost variance. The variance of project cost outcomes associated with an integration time fraction of 0.1 is $0.025 million. With an ideal integration time fraction of 0.5 the variance is $0.463 million. Simpler projects suffer less cost variance. Finally, it can be seen that the simpler projects actually meet the sponsor's expectations of saving money by negotiating a cheaper price. At $60/eng*hr the project cost is $21.04 million, while at $100/eng*hr the project cost is $21.29 million (see Table 4 below).

Agreed Contract Rate ($/eng*hr)	Integration Fraction Time	Integration Fraction Time	Integration Fraction Time	Integration Fraction Time	Integration Fraction Time		
	0.1	0.2	0.3	0.4	0.5	Average	Variance
60	21.04	21.27	21.61	22.9	22.76	21.92	0.591784
70	21.35	21.45	21.64	21.92	22.28	21.73	0.113896
80	21.41	21.4	21.41	21.5	21.85	21.51	0.029544
90	21.35	21.22	21.09	21.2	21.24	21.22	0.00692
100	21.29	21.05	20.91	20.88	20.66	20.96	0.043176
110	21.42	21.2	21.18	21.28	21.32	21.28	0.00752
120	21.58	21.4	21.48	21.74	22.05	21.65	0.05288
130	21.78	21.64	21.82	22.27	22.86	22.07	0.199104
Average	21.4	21.33	21.39	21.71	21.88		
Variance	0.02482449	0.032477551	0.087812245	0.191097959	0.463726531		

Table 4. Project Sponsor Cost ($M) – Varying Project Complexity (Ideal Fraction Integration Time)

8.0 Discussion

Assumptions

The results described above carry with them certain assumptions. It is useful to restate these before considering more broadly the implications of the results. First, that oil and gas development projects feature complex product systems that are highly integral in nature. Second, the development of these product systems requires significant investment in integration activities by the firms engaged in their delivery. Third, that the motivation for the investment in integration is developed through relationships based on trust and mutual goals. Finally, that the firms engaged in a project organization, sponsor and contractor, act to create value for their shareholders by taking what they perceive as the appropriate actions. Linking these assumptions together generated the causal structures described in chapter four. Modeling these relationships in a system dynamics model and applying the motivation of financial self-interest to each of the firms engaged in the project (sponsor and contractor) allowed a number of findings to become evident.

Findings

The key findings from the research were:

1. Projects developing complex integral product systems display price sensitive "tipping-point" behavior.
   1.1 Securing the most cost effective solution for a project may involve carrying higher initial, lump-sum, costs.

1.2 Projects with contractors operating close to the price sensitive region are highly volatile.

2 Complex projects (those requiring significant integration efforts) are more sensitive to price driven behaviors than simpler architectures.

This second point, and the price sensitive tipping point, can be seen clearly in the following figure. The plot shows a three dimensional map of the project space with project costs on the vertical axis. This cost is a function of both the agreed contract rate and the project complexity.

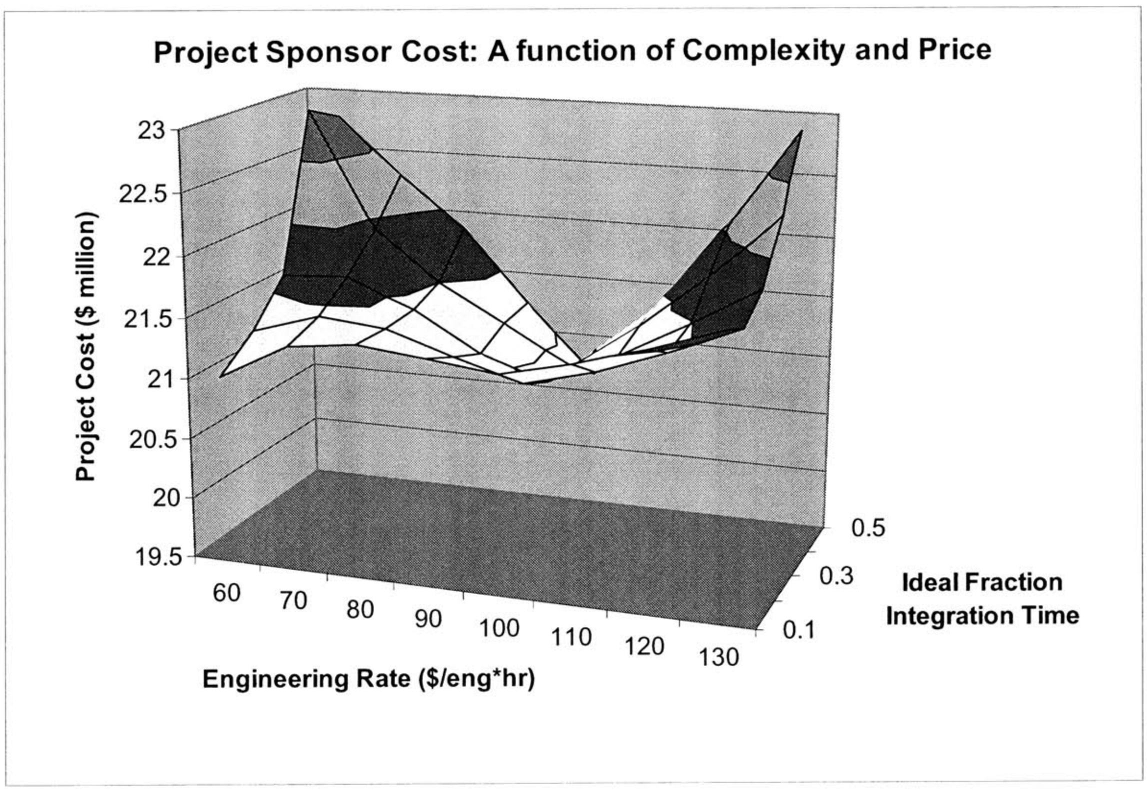

Figure 41. The Price Sensitive Tipping Point

It is instructive to examine these findings in relation to the case study presented in chapter five. The outcomes experienced on the Milton project appear to provide some evidence for the notion of a price sensitive tipping point. A number of the contractors selected that had problems in executing their contracts were also noted as being remarkable cheap in relation to their competitors. We are unable to determine whether these firms would still have had problems had their prices been higher, or to what extent the bid prices reflected a lack of understanding of the cost of the job rather than an attempt to "buy" the work by driving down costs. However, it still remains the case that these contractors were described by Big Oil management as being revenue/resource constrained in their ability to deliver on their promises.

The results from the sensitivity analysis showed that, for a number of variables tested, projects operating below the contractors "preferred" returns demonstrate more variance of outcomes. This volatility suggests that projects operating thusly are more likely to generate undesirable behavior in the face of perturbations such as late changes and the like. In addition, and quite intriguingly, the results indicated that projects which are developing highly integral product architectures are more susceptible to the dynamics investigated than simpler systems. This finding has a number of implications for the design of projects organizations. The establishment of the project organization is frequently carried out without detailed reference to the complexity of the underlying product systems (in at least that while the contracts are written to ensure that the project teams are established with the technical requirements considered, the financial aspects of the complexity are treated separately). Deeper understanding of the results, and the findings derived from them, can be gained through approaching them with a number of different frameworks.

Relational and Formal Contracts

The enterprise established to execute major oil and gas projects is assembled through a mix of formal and relational contracts. Formal contracts are those that can be enforced by a third party, for example the courts, and are specified *ex ante* in terms that can be verified *ex post* (Baker, Gibbons and Murphy 2002). For oil and gas development projects these are the formal mechanisms that define the project scope, its costs and the scope change mechanisms such as variation orders. Relational contracts are "informal agreements sustained by the value of future relationships"[32]. As presented by Baker, Gibbons and Murphy (2002) relational contracts are an essential (some would argue *the* essential) mechanism for circumventing difficulties in formal contracts. They are sustained by the promise or expectation of future working relationships between agents, and the value derived from these relationships. Relational contracts are therefore a very important mechanism between the project sponsor and the contractor(s). Sharing of knowledge and requirements, attendance of meetings and efficacious delivery of information are all attributes of the relational contracts that exist between firms engaged in the delivery of a project. In the model presented in this thesis the relational contract was represented by the *Relationship Index* that informed the amount of time devoted to integration activities. The formal contract was represented by the cost and pricing mechanisms of the lump sum price and variation order revenue. It could be argued that the use of variation orders, which occurred as a result of a deteriorating relationship, reflect the trade-off being made between the value of one contract form and another. Reneging on the relational contract invoked the use of the formal mechanisms. The

[32] Baker G., Gibbons R., Murphy K, J., 2002, pg 39.

"tipping point" therefore also reflects a shift away from informal mechanisms towards more formal ones.

In a project enterprise a network of formal and relational contracts exists. The project sponsor formally contracts with various contractors to deliver portions of the project such as the fabrication of the hull, design of the topsides, fabrication of the topsides, design of the subsea system, installation of the facility offshore etc. Both formal and relational contracts exist between the sponsor and each of the contractors. However, in most project teams only relational contracts exist between the contractors. The diagram below indicates this structure. Formal (F) contracts exist between the sponsor (SP) and each of the contractors (C1, C2, C3). Relational contracts (R) also exist between the sponsor and each of the contractors. The three contractors are linked only through the formal contracts to the sponsor and through relational contracts to each other. In reality the project could involve a dozen or so contractors with some being "second tier" suppliers to the primary contractors and thus sharing formal contracts as well. The diagram shows a very simplified representation of the network.

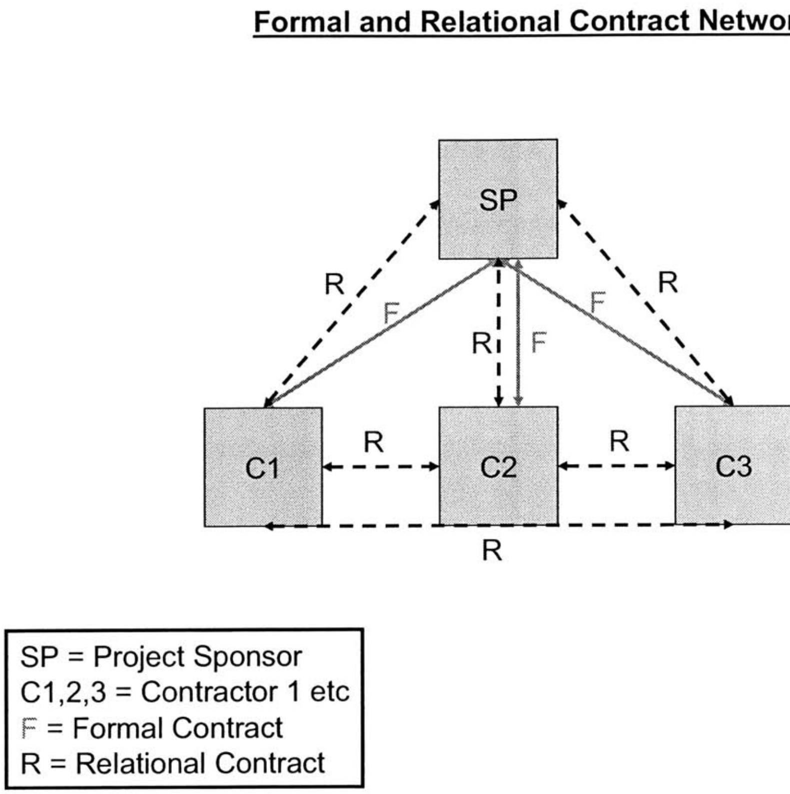

Figure 42. Contract Networks

In the oil and gas industry there are only a handful of firms that have the required skills and assets to execute the projects. As a result the firms tend to work together on different projects repeatedly. This helps establish the relational contracts. However, the cost of reneging on these relational contracts is highly variable. Where these firms are not in competition the cost of reneging may be sufficiently high to encourage cooperation between them. In many cases though the firms, while working together on the current project, may be in direct competition for the next development. In these cases the cost of reneging on the relational contract that exists between the contractors may be very low (indeed there may even be incentives to do so, i.e. by withholding information the firm may be able to advantage itself relative to its competitors). Only the formal and relational contracts to the project sponsor provide the cohesive mechanisms.

The research findings suggest that beyond a price sensitive tipping point project execution becomes increasingly difficult. The consequences include a reduction in the time a contractor will devote to integration activities. Consideration of this finding, in conjunction with the environment of networked relational contracts, suggests the possibility of the project experiencing "contractor contagion".

If one contractor reneges on the relational contract with the sponsor it follows that they will also, or are likely to, renege on the relational contracts between the contractors. The manifestation of this reneging, as represented in this model, is shifting resources away from integration activities. This has consequences for other contractors working on highly integral systems and invokes the "variation order – communication loop" shown in chapter four. As integration meetings usually involve several of the firms engaged on the contract, limiting effort in this area affects their work as well. Through this mechanism we can see how the dynamics shown in chapter four could "spread" from contractor to contractor once an initial disruption (the initial reneging) occurs. The idea of "contractor contagion" is analogous to the "fire fighting" dynamic within the single firm, multi-project environment (Repenning 2002), suggesting an opportunity for further research.

Alignment

The findings of the research can be framed in terms of alignment between the contractor's and project sponsor's incentives. Alignment of the incentives between firms is achieved when the risks, costs and rewards of doing business are distributed fairly across the network (Narayanan and Raman 2004). In the thesis model the alignment between sponsor and contractor can be characterized as somewhat orthogonal. At first approximation it can be seen that the firms behave as if the financial incentives are not aligned. When project sponsors drive down the initial lump-sum cost of a project, this is clearly at the expense of the contractor's financial position. When contractors invoke variation orders to secure revenue, this is not in the financial interests of the sponsor. This creates an adversarial relationship which is an essential element of the enterprise architecture delivered by the contractual relationship. The misalignment between the sponsor and contractor generates additional expense for the sponsor which can be viewed as a transaction cost.[33]

Putting to one side issues of risk, and alignment of risk (other than financial risk), the contractor and sponsor are aligned in some respects. For example, from a relational contract perspective, both firms want the project to succeed. The contractor wants to improve their standing with the sponsor and win future work, as well as more generally have the success of the project recognized and thus build a favorable reputation in the market place. From the project sponsor's perspective, a successful project and

[33] The contractor also faces transaction costs from delays and variation order generation. As the project drags on, this limits the ability of the firm to bid on the next project and the opportunity cost of missing out on additional work represents a transaction cost.

relationship with the contractor lowers the transaction cost of future relationships. For example, by lowering the information search cost when selecting contractors for future developments. This explains the characterization of the alignment as *somewhat* orthogonal. Perceptions of the financial alignment are at odds, while the incentives based on relational contracts are reasonably aligned. It is important to note that the results suggest that understanding the full implications of the price-sensitive tipping point would allow for the misalignment of financial incentives to be recognized for what it is; an artifact of the behavior of the system.

This suggests that alignment of incentives requires an alternative enterprise architecture. The orthogonal architecture, characterized by an adversarial element, may be improved by moving to a more fully aligned architecture. Recognizing that the misalignment exists within a spectrum of possible solutions provides an opportunity to address it. Under the structure modeled in the thesis a number of project pricing solutions deliver improved project performance in comparison to the "zero-sum game" approach of minimizing up front costs. However, it is not explicitly evident to the project sponsor and contractor that alternatives exist. Different enterprise architectures, an alliance or joint venture structure for example, may make the tradeoffs explicit and allow for the misalignment to be minimized.

Implications for Practitioners

As discussed above, the findings carry the promise of significant benefits for project managers and the firms engaged in large engineering projects. The existence of tipping point behavior related to pricing forces a shift away from the zero-sum game approach alluded to above. The implications of this are profound. Pushing for the lowest price carries significant risks, however the sponsors are wary of allowing the contractors to capture an inappropriate share of the economic rent from a project. The optimal pricing point for the project exists in a region near the contractors "preferred" pricing structure (i.e the price at which they make their normal desired returns). Negotiating the fair, and optimal price, for the contract requires understanding that all parties need to be financially rewarded for their participation. This suggests a far more open relationship than is currently the norm. Studies of successful inter-firm relationships, usually in a supply chain context, indicate that when firms develop close and consistent relationships they often involve an "open book" philosophy, and an expectation of secure long term partnerships (Womack, Jones and Roos 1991).

If project sponsors still choose to push for the lowest possible up front prices, and relationship durations only as long as the next competitive bid, then this decision should be made taking into account the following:

1 Projects operating in the price sensitive region are essentially unstable in the face of changes. Therefore, a great deal of effort must be put into front end loading (FEL) to ensure that the number of project changes is kept to an absolute minimum.

2 The lowest cost solutions are robust only for simple projects that are not highly integral. For some projects in which the scope is very clear, and unlikely to change, and which represent "standard" applications of technology then a low cost solution may be appropriate.

3 Delaying approval of variation orders increases the delays, and problems, for a project. Project managers, when faced with increasing numbers of variation orders, should consider expediting approval to give the project a chance to move ahead. This will aid in restoring the relationship between the contractor and sponsor in addition to relieving the resource pressure that exists as both teams devote energy to the management of the variation orders.

While the discussion above sets out some steps to deliver effective projects, the winning approach is best summed up by a quote from a senior project manager given when discussing how best to manage projects:

"projects that are approached as a win-win are very successful"

8.1 Future Research Directions

A number of issues were raised by the results that require further research. First, the notion of "contractor contagion" requires further investigation. Virtually all projects of any significance are executed by teams of contractors and it is worthwhile understanding to what extent problems for one contractor transfer to other members of the project team, and how that occurs. Second, alternative enterprise architectures and structures that provide for improved alignment of incentives need research. It is proposed in the next stage of this research endeavor that "alliance" project organizations will be investigated. Third, the impact that integral product system architecture has on project performance and the relationship to appropriate contract structures warrants serious study. As indicated in the results, the level of effort required for integration has significant influence on the project outcome. Finally, misalignment between firm incentives as a transaction cost and the implication this has on the question of integration of resources is worthy of further consideration. For firms that are regularly delivering complex projects as part of their business, it makes sense to consider the value implications for the integration of the services they depend on.

9.0 Conclusions

Project based organizational structures are utilized in many industries, and on many scales. This thesis has principally been interested in understanding how the contracting relationship influences the performance of large engineering projects. A simple system dynamics project model was developed with the addition of an explicit representation of the relationship between the contractor and project sponsor, including the variation order generation and revenue process. The model was informed by a case study of a series of major projects carried out by an oil and gas major. The results of the research supported the view that the contracting relationship, and in particular the initial negotiated price, can have a profound effect on the project's performance. A number of interesting findings emerged, not least of which being that the project model demonstrated a price sensitive "tipping point" in its outcomes. The results also indicated that the relative sensitivity of the project to the contracting relationship is in part dependent on the degree of integration/complexity demonstrated by the underlying product system.

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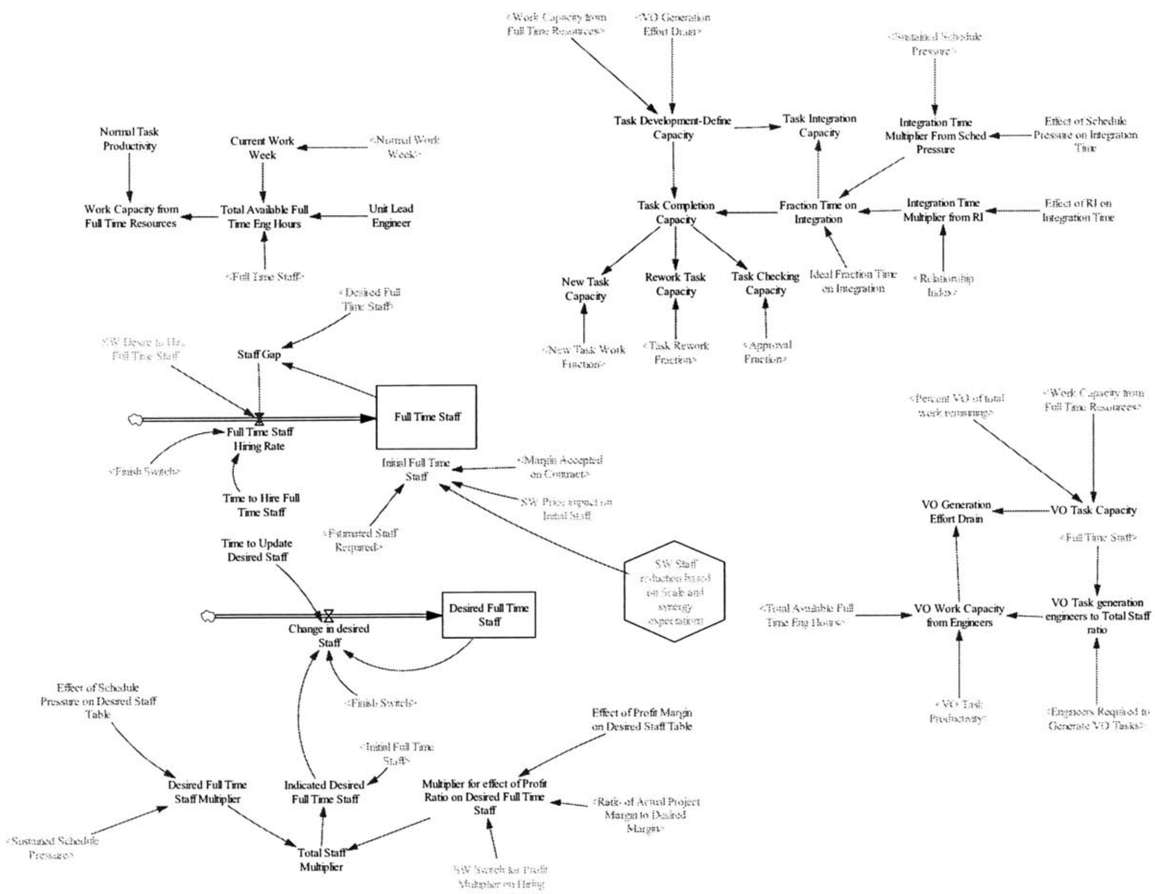
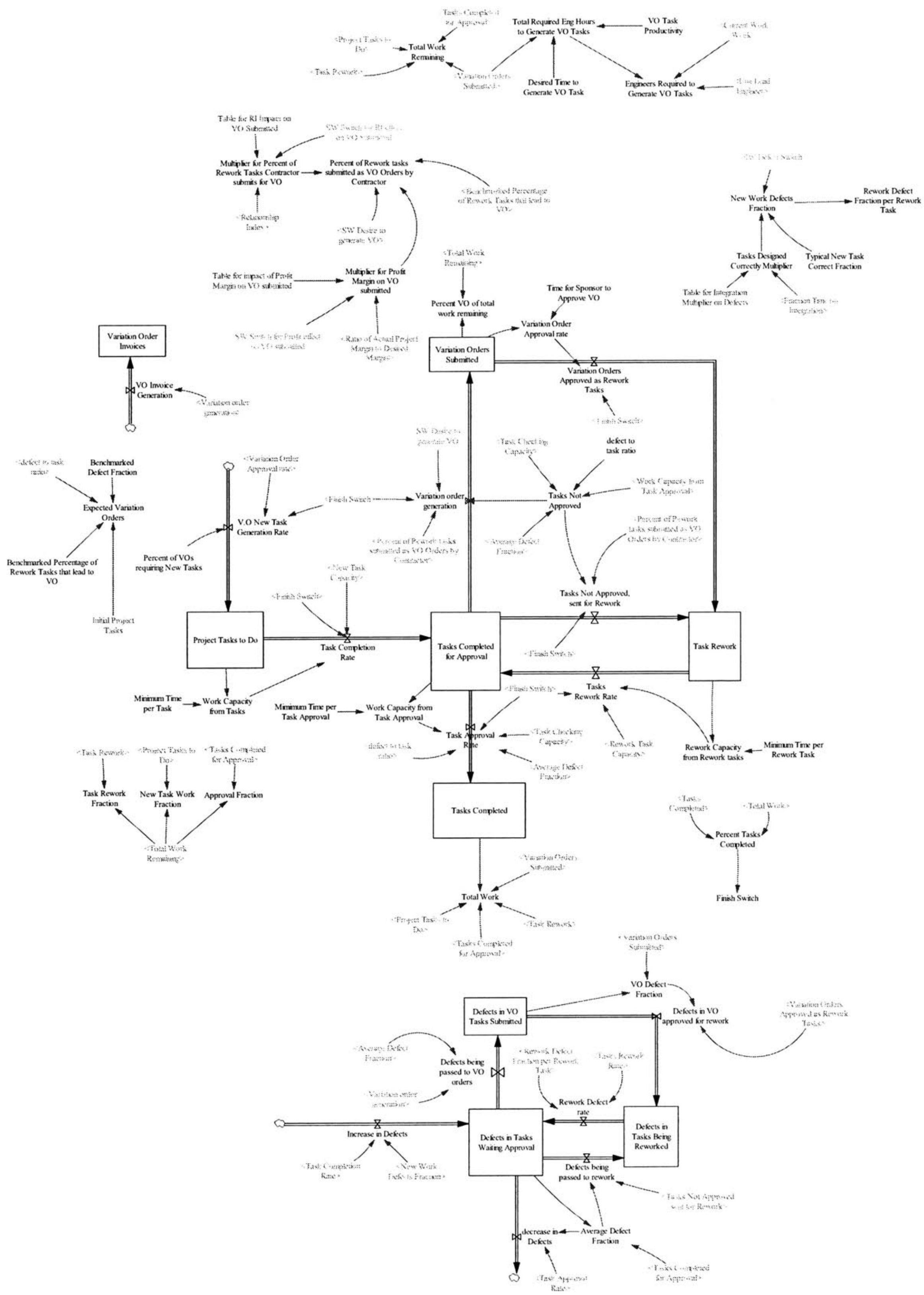
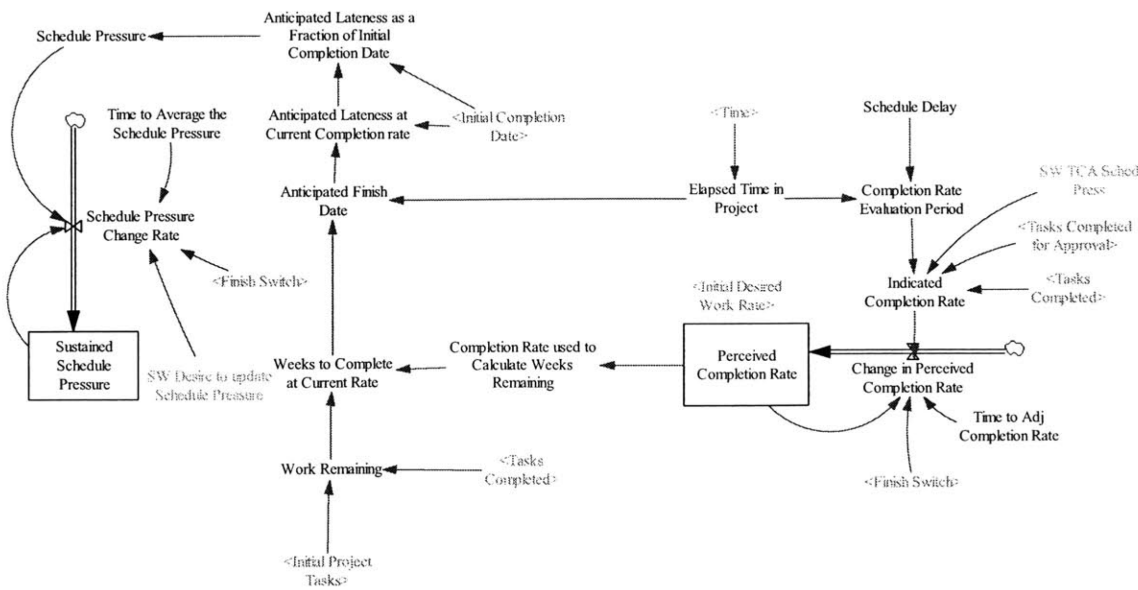
Appendix A: Model Documentation



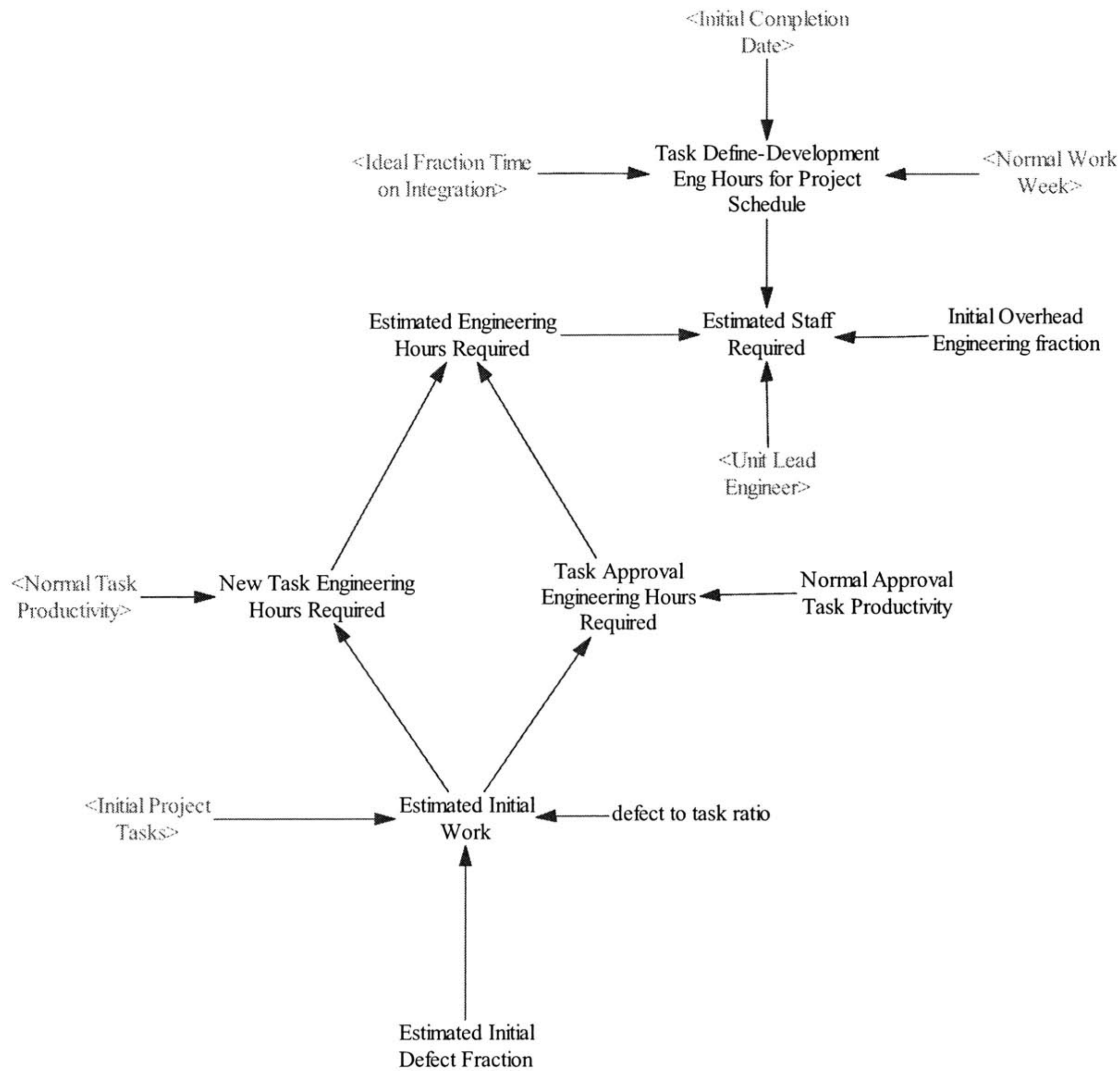
Staff Resources


Total Required Eng Hours to Generate VO Tasks
VO Task Productivity
Total Work Remaining
Desired Time to Generate VO Task
Engineers Required to Generate VO Tasks
Table for RI impact on VO Submitted
Multiplier for Percent of Rework Tasks Contractor submits for VO
Percent of Rework tasks submitted as VO Orders by Contractor
New Work Defects Fraction
Rework Defect Fraction per Rework Task
Tasks Designed Correctly Multiplier
Typical New Task Correct Fraction
Table for impact of Profit Margin on VO submitted
Multiplier for Profit Margin on VO submitted
Percent VO of total work remaining
Time for Sponsor to Approve VO
Variation Order Approval rate
Variation Order Invoices
Variation Orders Submitted
Variation Orders Approved as Rework Tasks
VO Invoice Generation
defect to task ratio
Benchmarked Defect Fraction
Expected Variation Orders
Variation order generation
Tasks Not Approved
V.O New Task Generation Rate
Benchmarked Percentage of Rework Tasks that lead to VO
Percent of VOs requiring New Tasks
Tasks Not Approved, sent for Rework
Project Tasks to Do
Task Completion Rate
Tasks Completed for Approval
Task Rework
Tasks Rework Rate
Minimum Time per Task
Work Capacity from Tasks
Minimum Time per Task Approval
Work Capacity from Task Approval
Task Approval Rate
Rework Capacity from Rework tasks
Minimum Time per Rework Task
Task Rework Fraction
New Task Work Fraction
Approval Fraction
Tasks Completed
Percent Tasks Completed
Finish Switch
Total Work
VO Defect Fraction
Defects in VO Tasks Submitted
Defects in VO approved for rework
Defects being passed to VO orders
Rework Defect rate
Increase in Defects
Defects in Tasks Waiting Approval
Defects in Tasks Being Reworked
Defects being passed to rework
decrease in Defects
Average Defect Fraction

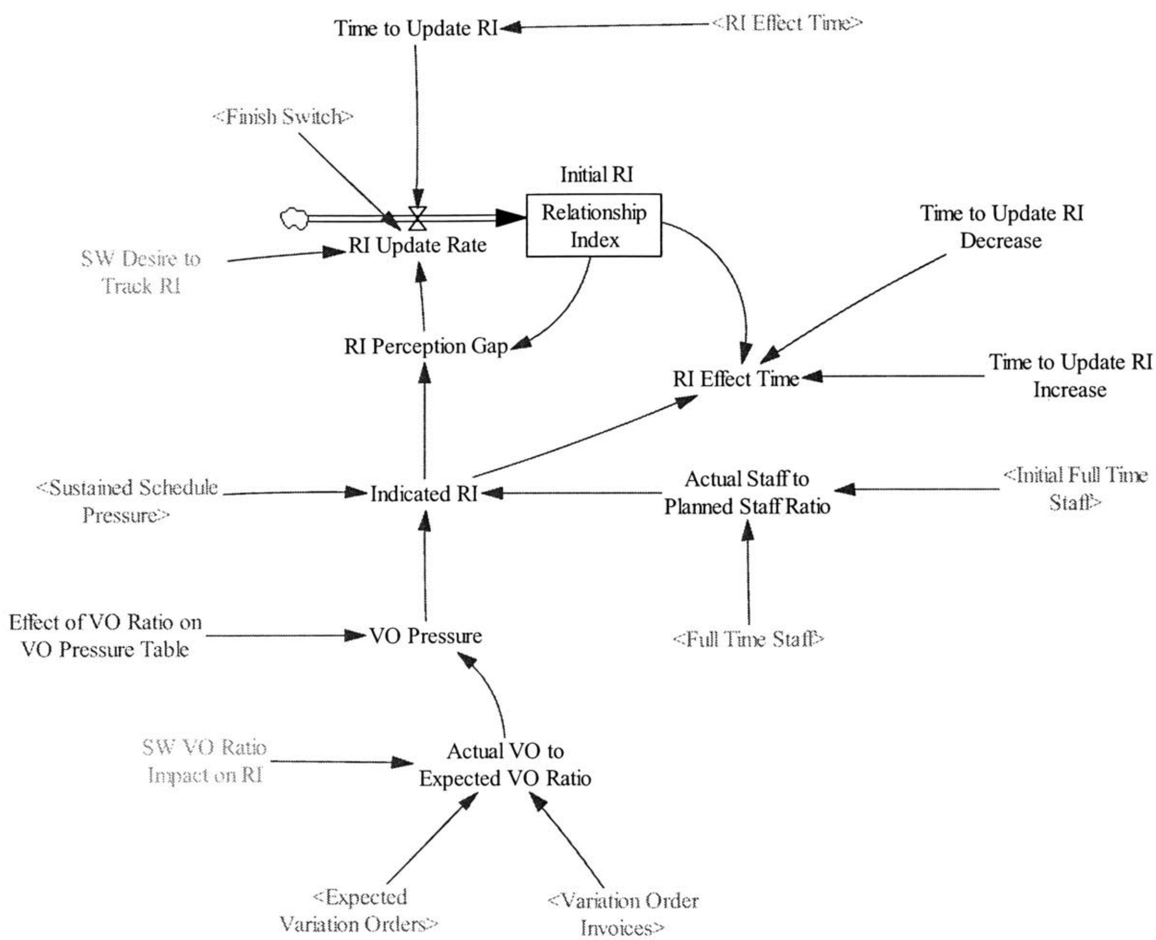
Work Flow



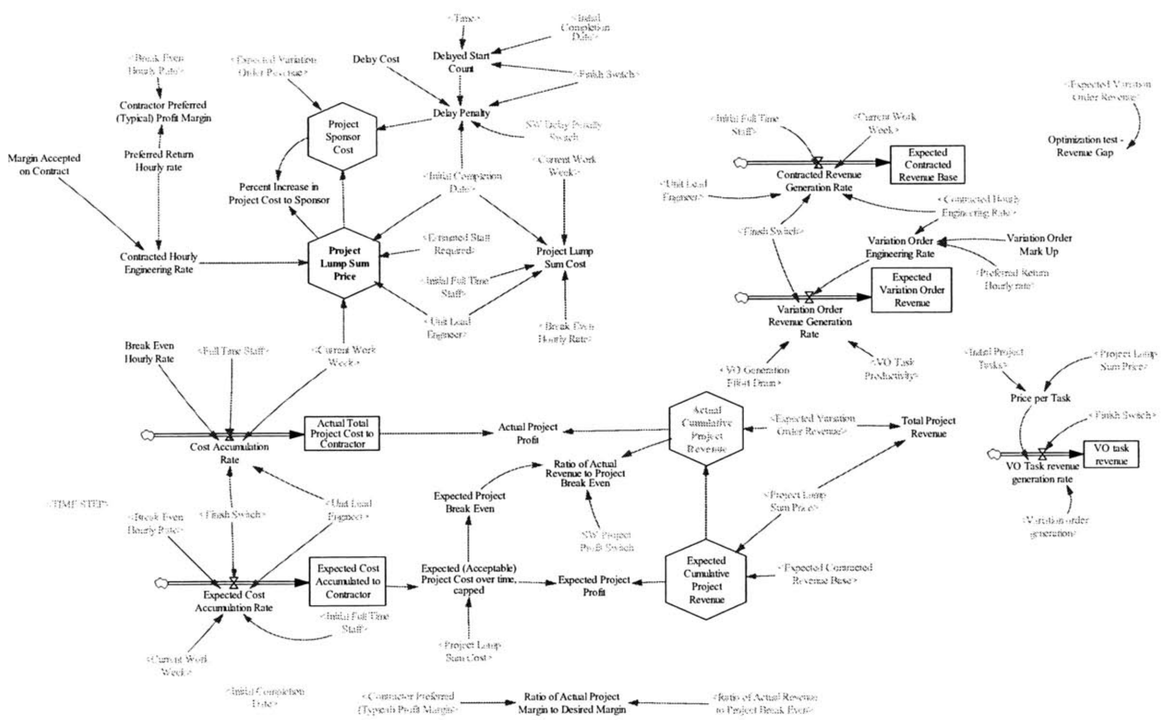
Schedule Pressure



Initial Staff Estimation



Relationship Index



Cost & Revenue

Model Text File

SW Switch for RI effect on VO Submitted=
1
~ Dmnl
~ Switch to activate the effect of the relationship on VO submission
|

Multiplier for Percent of Rework Tasks Contractor submits for VO=
IF THEN ELSE(SW Switch for RI effect on VO Submitted=1, Table for RI Impact on VO Submitted(Relationship Index), 1)
~ Dmnl
~ Multiplier that results as a function of the relationship between contractor and project sponsor. It modifies the percentage of rework tasks that the contractor submits VOs for.
|

Effect of VO Ratio on VO Pressure Table(
[(0,0)-
10,3)],(0,0),(1,1),(1.71254,1.49123),(2.47706,1.92982),(3.63914,2.32456),(5,2.5),(7.5,2.5
),(10,2.5))
~ Dmnl
~ This look-up function maps the effect of VO submission on the RI
|

VO Pressure=
Effect of VO Ratio on VO Pressure Table(Actual VO to Expected VO Ratio)
~ Dmnl
~ Multiplier for the effect of VO submitted - more VOs lead to higher pressure and a worsening relationship
|

Indicated RI=
1/(VO Pressure*Sustained Schedule Pressure*Actual Staff to Planned Staff Ratio)
~ Dmnl
~ The indicated RI is generated from the Schedule Pressure (high pressure leads to low RI), VO Pressure (high VO submission leads to low RI) and the Staff Ratio (higher staff than expected leads to a reduced RI)
|

SW Price impact on Initial Staff=
1
~ Dmnl
~ Turns on the effect of the Margin Accepted in reducing the Initial Staff
|

Initial Full Time Staff=
(MIN(Estimated Staff Required,Estimated Staff Required*IF THEN ELSE(SW Price impact on Initial Staff = 1 , Margin Accepted on Contract, 1)))*SW Staff reduction based on Scale and synergy expectations
~ engineer
~ Initial full time staff is calculated from the estimated staff and then modified with respect to the margin accepted on the contract. Lower margins means reduced initial staff numbers.
|

"Optimization test - Revenue Gap "=
5.4e+006-Expected Variation Order Revenue
~ $
~ Variable for Optimization Tests
|

Price per Task=
Project Lump Sum Price/Initial Project Tasks
~ $/Tasks
~ Cost of each task, based on agreed Price and Initial task numbers
|

Percent Increase in Project Cost to Sponsor=
(Project Sponsor Cost/Project Lump Sum Price)*100
~ Dmnl
~ The percent increase in project cost
|

VO Task revenue generation rate=
Variation order generation*Price per Task*Finish Switch
~ $/Week
~ Rate at which the cost of VOs generated
|

VO task revenue= INTEG (VO Task revenue generation rate,0)
~ $
~ Revenue generated by the VO tasks accumulating
|

SW VO Ratio Impact on RI=
1
~ Dmnl
~ Switch to activate the effect of VO submission on RI
|

Project Lump Sum Price=

Contracted Hourly Engineering Rate*Current Work Week*Initial Completion Date*Estimated Staff Required*Unit Lead Engineer

~ $

~ Lump Sum agreed to by the project sponsor. Calculated by the Contractor based on initial staffing estimates, agreed rate and schedule.

|

Variation Order Invoices= INTEG (VO Invoice Generation,0)

~ Tasks

~ The total Number of Variation Orders generated over the project - a cumulative total of Invoices

|

Actual VO to Expected VO Ratio=

IF THEN ELSE(SW VO Ratio Impact on RI=1,Max(1,zidz(Variation Order Invoices,Expected Variation Orders)) , 1)

~ Dmnl

~ The ratio of actual VO generated on the project to the anticipated number of VOs

|

VO Invoice Generation=

Variation order generation

~ Tasks/Week

~ Rate at which variation orders are generated

|

SW TCA Sched Press=

0

~ Dmnl

~ Switch to include Tasks Completed for Approval in calculating the schedule pressure. "Progress" can be calculated based on either just the Tasks Completed, or inclusive of those tasks that are awaiting approval.

|

Indicated Completion Rate=

(Tasks Completed+(SW TCA Sched Press*Tasks Completed for Approval))/Completion Rate Evaluation Period

~ Tasks/Week

~ Indicated rate at which the tasks are being completed based on elapsed time

|

Delay Penalty=

(IF THEN ELSE(Finish Switch>0, (Delayed Start Count-Initial Completion Date)*Delay Cost, 0))*SW Delay Penalty Switch

~ $
~ This is the Opportunity Cost of Project Delay - i.e loss of Sponsor Revenue from not having the plant producing goods.
|

SW Delay Penalty Switch=
0
~ Dmnl
~ Switch to turn on the Delay Penalty of opportunity cost for the Project \ Sponsor from the project being delayed.
|

New Work Defects Fraction=
(1-Tasks Designed Correctly Multiplier*Typical New Task Correct Fraction)*SW Defect Switch
~ Defects/Tasks
~ Percent of new work tasks that are designed with defects
|

Percent of Rework tasks submitted as VO Orders by Contractor=
MIN(1,Multiplier for Percent of Rework Tasks Contractor submits for VO*Benchmarked Percentage of Rework Tasks that lead to VO*SW Desire to generate VO*Multiplier for Profit Margin on VO submitted)
~ Dmnl
~ Includes switch to turn VO generation desire on
|

Typical New Task Correct Fraction=
0.85
~ Defects/Tasks
~ Under "ideal" conditions (i.e 40% of time on integration) it is expected that 85% of New Tasks are Correctly delivered first time
|

Tasks Designed Correctly Multiplier=
Table for Integration Multiplier on Defects(Fraction Time on Integration)
~ Dmnl
~ Multiplier that captures the effect of investing in integration activities on defect rates.
|

Delayed Start Count=
(IF THEN ELSE(Finish Switch>0, Time*Finish Switch, 0))+(IF THEN ELSE(Time<Initial Completion Date, Initial Completion Date-Time, 0))
~ Week

~ This is a counter for the weeks that occur AFTER the initial completion date. A counter of the Project Delay.

|

Indicated Desired Full Time Staff=

Max(Initial Full Time Staff,Total Staff Multiplier*Initial Full Time Staff)

~ engineer

~ The Desired Full Time as modified by the schedule pressure (wanting to hire) and the Profitability of project (resisting hire)

|

Total Staff Multiplier=

Desired Full Time Staff Multiplier*Multiplier for effect of Profit Ratio on Desired Full Time Staff

~ Dmnl

~ Combined multiplier for effects of profit margins and schedule pressure

|

Expected Project Break Even=

"Expected (Acceptable) Project Cost over time, capped"

~ $

~ Project break even is the total cost of the project capped at the Lump Sum cost

|

Multiplier for effect of Profit Ratio on Desired Full Time Staff=

IF THEN ELSE(SW Switch for Profit Multiplier on Hiring = 1, Effect of Profit Margin on Desired Staff Table (Ratio of Actual Project Margin to Desired Margin), 1)

~ Dmnl

~ Multiplier that results from the effect of the ratio of actual project profit to desired profit.

|

Ratio of Actual Revenue to Project Break Even=

zidz(Actual Cumulative Project Revenue,Expected Project Break Even)*SW Project Profit Switch

~ Dmnl

~ Ratio of the revenue from the project to the project break even. Gives a measure of the performance of the project from the Contractors perspective

|

"Contractor Preferred (Typical) Profit Margin"=

Preferred Return Hourly rate/Break Even Hourly Rate

~ Dmnl

~ The "normal" hourly rate divided by the break even hourly rate indicates the typical or preferred profit margin for the Contractor

|

Ratio of Actual Project Margin to Desired Margin=
zidz(Ratio of Actual Revenue to Project Break Even,"Contractor Preferred (Typical) Profit Margin")
~ Dmnl
~ Measures the ratio of actual achieved margin to the desired margin. When this ratio = 1 then we are achieving a margin that equates with the desired $100/$70 return expected.
|

Multiplier for Profit Margin on VO submitted=
IF THEN ELSE(SW Switch for Profit effect on VO submitted = 1,Table for impact of Profit Margin on VO submitted (Ratio of Actual Project Margin to Desired Margin), 1)
~ Dmnl
~ Modifies the strength of the use of VOs as a percent of rework base on profitability of the project
|

Delay Cost=
200000
~ $/Week
~ The cost of the project being delayed. This can be thought of as lost revenue, from lost sales of the product being developed, time cost of money, etc
|

Project Sponsor Cost=
Project Lump Sum Price+Expected Variation Order Revenue+Delay Penalty
~ $
~ Cost to the Project Sponsor is the Lump Sum Cost plus the Variation Orders plus the Opportunity Cost for delay.
|

Variation Order Engineering Rate=
Max(Variation Order Mark Up*Preferred Return Hourly rate,Contracted Hourly Engineering Rate)
~ $/(engineer*hour)
~ Variation Orders are charged at the Highest of the Preferred rate or the Contracted Rate
|

Variation Order Revenue Generation Rate=
(VO Generation Effort Drain*Variation Order Engineering Rate/VO Task Productivity)*Finish Switch
~ $/Week

~ Rate at which VO Tasks generate Revenue for the Contractor
|

Full Time Staff= INTEG (+Full Time Staff Hiring Rate,Initial Full Time Staff)
~ engineer
~ The total staff on the Project
|

Variation Order Mark Up=
1.5
~ Dmnl
~ Mark Up for Variation Orders over normal rate
|

Actual Project Profit=
Actual Cumulative Project Revenue-Actual Total Project Cost to Contractor
~ $
~ The actual contractors profit as generated by project revenues from VOs and agreed rate and project costs.
|

SW Project Profit Switch=
1
~ Dmnl
~ Switch to turn on profit accounting ratio
|

Table for impact of Profit Margin on VO submitted(
[(0,0)-(3,3)],(0,3),(0.25,2),(0.5,1.5),(0.75,1.2),(1,1),(1.25,0.85),(1.5,0.75),(2.25\
,0.5),(3,0.5))
~ Dmnl
~ A table that modifies the eagerness to use VOs based on the profit of the project. When the project has 0 profit or less (losing money) 3.0 times as likely to use VOs. When we are double the expected profit - half as likely
|

Expected Project Profit=
Expected Cumulative Project Revenue-"Expected (Acceptable) Project Cost over time, capped"
~ $
~ Expected Contractor's Profit to be generated over the project. Based on initial staff assumptions and project durations.
|

"Expected (Acceptable) Project Cost over time, capped"=
MIN(Expected Cost Accumulated to Contractor,Project Lump Sum Cost)

~ $
~ The Expected Project cost to the Contractor expressed cumulatively over the project duration, but capped at the Lump Sum Cost
|

SW Switch for Profit effect on VO submitted=
1
~ Dmnl
~ Switch to isolate effect of profit ratio on submission of VOs
|

Effect of Profit Margin on Desired Staff Table(
[(0,0)-
(2,1)],(0,0),(0.15,0.15),(0.25,0.25),(0.5,0.5),(0.74,0.755),(0.911315,0.912281\
),(1,0.960526),(1.1682,0.986842),(1.4,1),(2,1))
~ Dmnl
~ Plots the desire to hire staff against profits. When the project is not making any profit there is no desire to hire staff.
|

SW Switch for Profit Multiplier on Hiring=
1
~ Dmnl
~ Switch to turn on the effect of profit ratio on hiring
|

Actual Cumulative Project Revenue=
Expected Variation Order Revenue+Expected Cumulative Project Revenue
~ $
~ Total revenue earned by Contractor includes the Lump Sum and Variation Order Revenue. The revenue accumulates over time (partial payments, milestone payments etc). For simplicity it is calculated over timestep.
|

Expected Cumulative Project Revenue=
MIN(Expected Contracted Revenue Base,Project Lump Sum Price)
~ $
~ At each time step, the Expected cumulative revenue for accounting purposes is the minimum of the Lump Sum and the Expected Revenue Base from the contracted Hourly Rate.
|

Project Lump Sum Cost=
Break Even Hourly Rate*Current Work Week*Initial Completion Date*Initial Full Time Staff*Unit Lead Engineer
~ $

~ Expected Cost of Project, calculated as a Lump Sum
|

Total Project Revenue=
Project Lump Sum Price+Expected Variation Order Revenue
~ $
~ |

VO Defect Fraction=
zidz(Defects in VO Tasks Submitted,Variation Orders Submitted)
~ Defects/Tasks
~ Average number of defects per VO submitted
|

Expected Cost Accumulated to Contractor= INTEG (Expected Cost Accumulation Rate,0)
~ $
~ Total Anticipated Costs to date
|

Defects in VO approved for rework=
Variation Orders Approved as Rework Tasks*VO Defect Fraction
~ Defects/Week
~ |

Contracted Revenue Generation Rate=
Contracted Hourly Engineering Rate*Current Work Week*Initial Full Time Staff*Unit Lead Engineer*Finish Switch
~ $/Week
~ Rate at which Contract revenue was expected to Accumulate
|

Expected Contracted Revenue Base= INTEG (Contracted Revenue Generation Rate,0)
~ $
~ Accumulating revenue to the contractor from agreed contract price
|

Expected Cost Accumulation Rate=
(Break Even Hourly Rate*Current Work Week*Initial Full Time Staff*Unit Lead Engineer)*Finish Switch
~ $/Week
~ Rate at which the Contractor expected costs to accumulate over the project
|

Expected Variation Order Revenue= INTEG (Variation Order Revenue Generation Rate,0)

~ $
~ Expected Revenue from VOs being approved and generating new tasks. The formulation for the VO Effort Drain captures amount of VO work and the engineering hours required.
|

Estimated Engineering Hours Required=
New Task Engineering Hours Required+Task Approval Engineering Hours Required
~ engineer*hour
~ Estimate of initial Engineering Hours required to complete the Initial Project Tasks
|

Defects being passed to rework=
"Tasks Not Approved, sent for Rework"*Average Defect Fraction
~ Defects/Week
~ |

Defects being passed to VO orders=
Average Defect Fraction*Variation order generation
~ Defects/Week
~ Rate of defect flow
|

Defects in Tasks Being Reworked= INTEG (Defects being passed to rework+Defects in VO approved for rework-Rework Defect rate,0)
~ Defects
~ Stock of defects in rework tasks (defects coflow)
|

Defects in Tasks Waiting Approval= INTEG (+Increase in Defects-decrease in Defects+Rework Defect rate-Defects being passed to VO orders-Defects being passed to rework,0)
~ Defects
~ Stock of defects in tasks awaiting approval (coflow of defects)
|

Defects in VO Tasks Submitted= INTEG (Defects being passed to VO orders-Defects in VO approved for rework,0)
~ Defects
~ Stock of defects based on VO submission (defects coflow)
|

Total Work Remaining=

Project Tasks to Do+Task Rework+Tasks Completed for Approval+Variation Orders Submitted
~ Tasks
~ Total work left in the project to complete
|

Estimated Staff Required=
((Estimated Engineering Hours Required/"Task Define-Development Eng Hours for Project Schedule")/Unit Lead Engineer)*(1+Initial Overhead Engineering fraction)
~ engineer
~ Initial estimated number of engineers based on # tasks, time spent on integration, estimated error rates and required completion date. Task time and productivity based on time to do an initial task. No inclusion of estimates of approval time. This corresponds with personal anecdotal evidence.
|

Preferred Return Hourly rate=
100
~ $/(engineer*hour)
~ The desired rate to deliver the return expected by shareholders
|

decrease in Defects=
(Task Approval Rate)*Average Defect Fraction
~ Defects/Week
~ |

Break Even Hourly Rate=
70
~ $/(engineer*hour)
~ The hourly rate required to cover the overheads, plant, facilities, vessels, debt repayments etc required by the contacting firm.
|

"Task Define-Development Eng Hours for Project Schedule"=
Initial Completion Date*Normal Work Week*(1-Ideal Fraction Time on Integration)
~ hour/engineer
~ This is the number of engineering hours available (per unit engineer) for the project duration at 40 hours per week less the time spent on integration.
|

New Task Engineering Hours Required=
Estimated Initial Work/Normal Task Productivity

~ engineer*hour
~ Engineering hours required to complete designs of the initial tasks
|

Project Tasks to Do= INTEG (-Task Completion Rate+"V.O New Task Generation Rate",Initial Project Tasks)
~ Tasks
~ Tasks the constitute the project
|

Increase in Defects=
Task Completion Rate*New Work Defects Fraction
~ Defects/Week
~ Rate at which defects flow into the stock of defects awaiting approval
|

Contracted Hourly Engineering Rate=
Margin Accepted on Contract*Preferred Return Hourly rate
~ $/engineer/hour
~ Rate at which engineers are billed to the project Sponsor
|

Cost Accumulation Rate=
(Current Work Week*Break Even Hourly Rate*Unit Lead Engineer*Full Time Staff)*Finish Switch
~ $/Week
~ Rate at which cost accumulates
|

Total Work=
Project Tasks to Do+Tasks Completed for Approval+Task Rework+Tasks Completed+Variation Orders Submitted
~ Tasks
~ The total sum of all the tasks that exist in the system at any point in time
|

Task Approval Engineering Hours Required=
Estimated Initial Work/Normal Approval Task Productivity
~ engineer*hour
~ Engineering hours required to approve the tasks
|

Margin Accepted on Contract=
0.6
~ Dmnl

~ Multiplier applied to the Preferred Hourly rate to derive the rate used for the Contacted Rate. This is a measure of the firms aggressiveness to win the work. More aggressive means reducing this number below 1. i.e a less than normal return in order to "win" the work.
|

Rework Defect rate=
Rework Defect Fraction per Rework Task*Tasks Rework Rate
~ Defects/Week
~ |

Normal Approval Task Productivity=
0.1
~ Tasks/(engineer*hour)
~ The % of Approval task completed per engineering hour spent. It takes approximately a quarter of the time to approve a task that it does to first do it per engineer.
|

Time to Update RI=
RI Effect Time
~ Week
~ Time to adjust the RI
|

Time to Update RI Decrease=
8
~ Week
~ When RI is decreasing the update time is shorter
|

RI Effect Time=
IF THEN ELSE(Indicated RI>Relationship Index , Time to Update RI Increase, Time to Update RI Decrease)
~ Week
~ Time to adjust the RI
|

RI Perception Gap=
Indicated RI-Relationship Index
~ Dmnl
~ The gap between the currently indicated RI and the immediate effect of the various pressure variables.
|

RI Update Rate=

((RI Perception Gap/Time to Update RI)*SW Desire to Track RI)*Finish Switch
~ 1/Week
~ Rate at which the RI is updated
|

Time to Update RI Increase=
16
~ Week
~ Acknowledgment of improving RI performance typically takes longer than a worsening performance.
|

Variation Orders Approved as Rework Tasks=
Variation Order Approval rate*Finish Switch
~ Tasks/Week
~ Rate at which VOs are approved and move to the stock of rework tasks
|

"Tasks Not Approved, sent for Rework"=
(Tasks Not Approved*(1-Percent of Rework tasks submitted as VO Orders by Contractor))*Finish Switch
~ Tasks/Week
~ Rate of tasks that are not approved being sent to rework.
|

"V.O New Task Generation Rate"=
(Variation Order Approval rate*Percent of VOs requiring New Tasks)*Finish Switch
~ Tasks/Week
~ The rate at which V.Os become tasks is the same rate at which they become approved. i.e once approved they move into the stock of V.O. approved as New Tasks
|

Tasks Not Approved=
MIN(Task Checking Capacity*Average Defect Fraction*defect to task ratio, Work Capacity from Task Approval*Average Defect Fraction*defect to task ratio)
~ Tasks/Week
~ The rate at which tasks do not get approved based on the minimum of the resource limit (Task Checking Capacity) or task limits (Work Capacity From Task Approval) and the Average Defect Fraction
|

Variation order generation=
((Percent of Rework tasks submitted as VO Orders by Contractor*Tasks Not Approved)*SW Desire to generate VO)*Finish Switch

~ Tasks/Week
~ The rate of VO generation as a function of rework rate and errors
|

Variation Order Approval rate=
Variation Orders Submitted/Time for Sponsor to Approve VO
~ Tasks/Week
~ Rate at which VOs are approved and move to the stock of rework tasks
|

Task Rework= INTEG (
"Tasks Not Approved, sent for Rework"-Tasks Rework Rate+Variation Orders Approved as Rework Tasks,0)
~ Tasks
~ Tasks that require rework on account of having defects
|

Tasks Completed for Approval= INTEG (+Task Completion Rate-Task Approval Rate-"Tasks Not Approved, sent for Rework"+Tasks Rework Rate-Variation order generation, 0)
~ Tasks
~ Tasks that have been completed and are awaiting approval
|

Percent of VOs requiring New Tasks=
0.5
~ Dmnl
~ Some VOs will require New Tasks to be defined (i.e work that was not included in the original scope), whereas some VOs are requests for additional resources/money to do rework tasks that have changed due to insufficient or changing data.
|

Average Defect Fraction=
zidz(Defects in Tasks Waiting Approval,Tasks Completed for Approval)
~ Defects/Tasks
~ Average defect fraction is the total stock of defects awaiting approval divided by the stock of tasks awaiting approval
|

Tasks Rework Rate=
(MIN(Rework Capacity from Rework tasks, Rework Task Capacity))*Finish Switch
~ Tasks/Week
~ The rate at which rework tasks get completed based on the minimum of the resource limit or task limits

|

Tasks Completed= INTEG (Task Approval Rate,0)

~ Tasks

~ Tasks that have been completed and approved as defect free

|

Task Approval Rate=

(MIN(Work Capacity from Task Approval*(1-Average Defect Fraction)*defect to task ratio, Task Checking Capacity*(1-Average Defect Fraction)*defect to task ratio))*Finish Switch

~ Tasks/Week

~ The rate at which tasks get approved based on the minimum of the resource limit (task Checking Capacity) or task limits (Work Capacity From Task Approval).

|

Variation Orders Submitted= INTEG (Variation order generation-Variation Orders Approved as Rework Tasks,0)

~ Tasks

~ Stock of variation orders that have been submitted by the contractor.

|

Total Required Eng Hours to Generate VO Tasks=

(Variation Orders Submitted/Desired Time to Generate VO Task)/VO Task Productivity

~ engineer*hour/Week

~ The total capacity of eng hours per week needed to generate the VO tasks in the time desired

|

Actual Total Project Cost to Contractor= INTEG (Cost Accumulation Rate,0)

~ $

~ Actual costs incurred by the contractor

|

Percent Tasks Completed=

zidz(Tasks Completed,Total Work)

~ Dmnl

~ Ratio of tasks completed against the total sum of work that exists

|

SW Defect Switch=

1

~ Dmnl

~ Switch to turn on defects

|

VO Task generation engineers to Total Staff ratio=
Engineers Required to Generate VO Tasks/Full Time Staff
~ Dmnl
~ Ratio of staff employed to generate VO tasks to the overall staff
|

Percent VO of total work remaining=
Variation Orders Submitted/Total Work Remaining
~ Dmnl
~ |

Desired Full Time Staff Multiplier=
Effect of Schedule Pressure on Desired Staff Table(Sustained Schedule Pressure)
~ Dmnl
~ Multiplier that results from the effect of schedule pressure
|

Desired Time to Generate VO Task=
2
~ Week
~ Generating a variation order takes the contractor a finite time and requires resources.
|

Effect of Schedule Pressure on Desired Staff Table(
[(0,0)-
(6,4)],(0,0.75),(0.432056,0.83908),(1,1),(1.46341,1.2069),(1.97909,1.58621),(\
2.4669,1.85057),(3,2),(4,2.1),(5,2.1))
~ Dmnl
~ Table that captures the effect of schedule pressure on the need for extra staff
|

VO Task Capacity=
Percent VO of total work remaining*Work Capacity from Full Time Resources
~ Tasks/Week
~ Work capacity dedicated to VO tasks
|

"Task Development-Define Capacity"=
Work Capacity from Full Time Resources-VO Generation Effort Drain
~ Tasks/Week
~ Capacity to carry out the non-VO tasks
|

VO Generation Effort Drain=
Max(VO Task Capacity,VO Work Capacity from Engineers)
~ Tasks/Week
~ The actual drain on the overall work effort from VO order Generation
|

Engineers Required to Generate VO Tasks=
(Total Required Eng Hours to Generate VO Tasks/Current Work Week)/Unit Lead Engineer
~ engineer
~ Given the number of VOs submitted, the desired time to turn these into submissions (and hence generate revenue) and the standard productivity, the number of engineers required to generate the Vo submissions can be calculated.
|

VO Work Capacity from Engineers=
Total Available Full Time Eng Hours*VO Task generation engineers to Total Staff ratio*VO Task Productivity
~ Tasks/Week
~ Work Capacity calculated from the number of engineers required to generate VO tasks
|

VO Task Productivity=
0.025
~ Tasks/(engineer*hour)
~ Variation order tasks are assumed to be similar to the standard project tasks in terms of their requirement for staff and time (hence the same productivity)
|

Task Completion Rate=
(MIN(Work Capacity from Tasks,New Task Capacity))*Finish Switch
~ Tasks/Week
~ The rate at which tasks get completed based on the minimum of the resource limit or task limits
|

SW Desire to generate VO=
1
~ Dmnl
~ Switch to turn on VO generation process
|

Change in Perceived Completion Rate=

((Indicated Completion Rate-Perceived Completion Rate)/Time to Adj Completion Rate)*Finish Switch

~ Tasks/Week/Week

~ Rate at which the completion rate is updated

|

SW Desire to Track RI=

1

~ Dmnl

~ Switch to activate RI

|

SW Desire to update Schedule Pressure=

1

~ Dmnl

~ Switch to calculate Schedule Pressure

|

Finish Switch=

IF THEN ELSE(Percent Tasks Completed>0.99, 0 , 1)

~ Dmnl

~ Switch to complete model run once 99% of tasks are completed

|

Change in desired Staff=

((Indicated Desired Full Time Staff-Desired Full Time Staff)/Time to Update Desired Staff)*Finish Switch

~ engineer/Week

~ Rate at which the desired staff level is updated

|

Full Time Staff Hiring Rate=

((SW Desire to Hire Full Time Staff*Staff Gap/Time to Hire Full Time Staff))*Finish Switch

~ engineer/Week

~ Rate at which staff are hired to meet the project's needs

|

Schedule Pressure Change Rate=

(((Schedule Pressure-Sustained Schedule Pressure)/Time to Average the Schedule Pressure)*SW Desire to update Schedule Pressure)*Finish Switch

~ 1/Week

~ Schedule Pressure changes over time - this is the rate at which it is averaged out over the project

|

Indicated Desired Staff=
Desired Staff Multiplier
~ engineer
~ |

Fraction Time on Integration=
MIN(1, Ideal Fraction Time on Integration*Integration Time Multiplier From Sched Pressure*Integration Time Multiplier from RI)
~ Dmnl
~ The multipliers for Schedule Pressure and RI combine to influence the amount of time invested in integration activities. The Ideal Fraction is modified by the two multipliers.
|

Effect of RI on Integration Time(
[(0,0)-
(2,2)],(0,0),(0.5,0.5),(0.75,0.75),(0.85,0.85),(0.923547,0.912281),(0.996942,\
0.964912),(1.12538,1),(2,1))
~ Dmnl
~ This look-up function maps the effect of the RI (Relationship Index) on the desire to invest time in integration activities.
|

Integration Time Multiplier from RI=
Effect of RI on Integration Time(Relationship Index)
~ Dmnl
~ Multiplier that results from the effects of the RI.
|

Actual Staff to Planned Staff Ratio=
Full Time Staff/Initial Full Time Staff
~ Dmnl
~ The ratio of actual staff to the expected staff has an impact on the relationship between the sponsor and contractor. More staff than expected leads to higher costs, lower margins etc. This impacts the relationship
|

Table for RI Impact on VO Submitted(
[(0,0)-(5,6)],(-0.0152905,5.92105),(0,4.5),(0.15,3),(0.25,2.5),(0.5,1.7),(0.8,1.2),(\
1,1),(1.2,0.8),(2.5,0.5),(5,0.5))
~ Dmnl
~ This look-up function maps the effect of the RI on the number of VOs submitted by the contractor
|

Benchmarked Defect Fraction=

0.15
~ Defects/Tasks
~ Anticipated percentage of defects based on historical norms
|

SW Staff reduction based on Scale and synergy expectations=
1
~ Dmnl
~ Initial staff numbers are affected by an expectation of synergies and scale if the project is large enough.
|

Current Work Week=
Normal Work Week
~ hour/Week/engineer
~ Normal work week is 40 hours
|

Relationship Index= INTEG (RI Update Rate,Initial RI)
~ Dmnl
~ A measure of the strength of the relationship between the contractor and project sponsor
|

Estimated Initial Defect Fraction=
0.15
~ Defects/Tasks
~ Estimate of defects based on previous experience (0.15)
|

Estimated Initial Work=
Initial Project Tasks/(1-Estimated Initial Defect Fraction*defect to task ratio)
~ Tasks
~ An estimate of the initial work which calculates the total work given the initial task list and an estimate of defects based on experience.
|

Expected Variation Orders=
Initial Project Tasks*Benchmarked Percentage of Rework Tasks that lead to VO*Benchmarked Defect Fraction*defect to task ratio
~ Tasks
~ The expected number of variation orders given expected defect rates and VO submission rates
|

Initial Overhead Engineering fraction=

0.1
~ Dmnl
~ A rule of thumb applied to estimate the "extra" effort required over and above the task completion effort associated with a project
|

Integration Time Multiplier From Sched Pressure=
Effect of Schedule Pressure on Integration Time(Sustained Schedule Pressure)
~ Dmnl
~ Multiplier that results from the effects of schedule pressure
|

defect to task ratio=
1
~ Tasks/Defects
~ Normalized at one defect per task
|

Benchmarked Percentage of Rework Tasks that lead to VO=
0.3
~ Dmnl
~ Percentage of rework tasks that typically result in variation order submission. Based on historical norms.
|

Initial RI=
1
~ Dmnl
~ |

Effect of Schedule Pressure on Integration Time(
[(0,0)-
(5,2)],(0,1),(1,1),(1.15,0.973684),(1.33028,0.877193),(1.5,0.75),(2,0.5),(3,0.25\
),(4,0.25))
~ Dmnl
~ This look-up function maps the effect of schedule pressure on the time invested in integration activities.
|

Anticipated Finish Date=
Elapsed Time in Project+Weeks to Complete at Current Rate
~ Week
~ The anticipated project finish date is based on time elapsed and weeks remaining at the current completion rate
|

Anticipated Lateness as a Fraction of Initial Completion Date=
Anticipated Lateness at Current Completion rate/Initial Completion Date
~ Dmnl
~ Lateness as a fraction of the overall project schedule. i.e 2 weeks late is not a big deal in a 200 week project, but is a real problem in a 12 week project.
|

Anticipated Lateness at Current Completion rate=
Anticipated Finish Date-Initial Completion Date
~ Week
~ The anticipated lateness of the project is the difference between the anticipated date and the initial project schedule
|

Approval Fraction=
Tasks Completed for Approval/Total Work Remaining
~ Dmnl
~ |

Completion Rate Evaluation Period=
Max(Elapsed Time in Project-Schedule Delay,1)
~ Week
~ Period over which the schedule progress is evaluated. Accounts for the fact that at the start of the project no work is expected to be completed immediately
|

Completion Rate used to Calculate Weeks Remaining=
Perceived Completion Rate
~ Tasks/Week
~ The perceived rate is used to calculate how many weeks will be required to finish the outstanding work
|

Current Desired Work Rate=
Total Work Remaining/Time Remaining
~ Tasks/Week
~ Work rate required based on work to be done and time remaining
|

Staff Gap=
Desired Full Time Staff-Full Time Staff
~ engineer
~ The gap between the current staff level and the desired staff
|

Weeks to Complete at Current Rate=
Work Remaining/Completion Rate used to Calculate Weeks Remaining
~ Week
~ The weeks left to complete the project based on the perceived completion rate
|

Task Rework Fraction=
Task Rework/Total Work Remaining
~ Dmnl
~ |

Sustained Schedule Pressure= INTEG (Schedule Pressure Change Rate,1)
~ Dmnl
~ This is the schedule pressure as felt by contractor and project sponsor.
|

Desired Full Time Staff= INTEG (Change in desired Staff,Initial Full Time Staff)
~ engineer
~ The desired staff to meet the project's needs
|

Desired Staff Multiplier=
Effect of Schedule Pressure on Staffing Table(Sustained Schedule Pressure)
~ Dmnl
~ |

Effect of Schedule Pressure on Staffing Table(
[(0,0)-(5,2)],(0,0.5),(0.5,0.7),(1,1),(1.25,1.1),(2,1.2),(3,1.25),(5,1.25))
~
~ |

Elapsed Time in Project=
Time
~ Week
~ Time counter for the weeks progressing
|

Task Checking Capacity=
Task Completion Capacity*Approval Fraction
~ Tasks/Week
~ Total task capacity is split proportionally to Checking Tasks based on % of Checking Tasks remaining
|

Task Completion Capacity=

"Task Development-Define Capacity"*(1-Fraction Time on Integration)
~ Tasks/Week
~ This is the available capacity to do work once time for integration activities is subtracted
|

Task Integration Capacity=
"Task Development-Define Capacity"*(Fraction Time on Integration)
~ Tasks/Week
~ The Task Integration Capacity is the amount of engineering hours devoted to integration activities which delivers a capacity measured in tasks/week..
|

Time to Update Desired Staff=
8
~ Week
~ Management takes time to update their estimates of the staff required during the project
|

Indicated Schedule Pressure=
Task Schedule Pressure*(Current Desired Work Rate/Normal Work Rate)
~ Dmnl
~ Modifies the task schedule pressure (how much has done of what was supposed to be done) with the amount of time left to do the remaining tasks
|

New Task Work Fraction=
Project Tasks to Do/Total Work Remaining
~ Dmnl
~ |

Time to Average the Schedule Pressure=
4
~ Week
~ Schedule pressure is calculated over a number of weeks to smooth for discrete events and transient noise.
|

Schedule Pressure=
1+Anticipated Lateness as a Fraction of Initial Completion Date
~ Dmnl
~ Schedule pressure is based on the percent lateness.
|

Ideal Fraction Time on Integration=

0.4
~ Dmnl
~ Initial percent of time expected to be spent on integration activities
|

Rework Task Capacity=
Task Completion Capacity*Task Rework Fraction
~ Tasks/Week
~ Total task capacity is split proportionally to Rework Tasks based on % of Rework Tasks remaining
|

Schedule Delay=
6
~ Week
~ Time lapse before work is expected to be completed and the completion rate is calculated
|

Time to Adj Completion Rate=
16
~ Week
~ Evaluating the completion rate takes time and is done in increments
|

Task Schedule Pressure=
XIDZ(Task Completion Schedule, Tasks Completed, 1)
~ 1
~ Ratio of scheduled task completion to actual task completion
|

New Task Capacity=
Task Completion Capacity*New Task Work Fraction
~ Tasks/Week
~ Total task capacity is split proportionally to New Tasks based on % of New Tasks remaining
|

Perceived Completion Rate= INTEG (Change in Perceived Completion Rate, Initial Desired Work Rate)
~ Tasks/Week
~ The perceived completion rate
|

Work Remaining=
Initial Project Tasks-Tasks Completed

~ Tasks
~ The outstanding work is nominally the initial tasks minus the tasks completed
|

Scheduled Percent total work completed=
(Task Completion Schedule/Initial Project Tasks)*100
~ 1
~ Scheduled % completed of project
|

Task Completion Schedule=
MIN(Initial Project Tasks, Initial Desired Work Rate*Time)
~ Tasks
~ Tasks completed as the project moves forward
|

Normal Work Rate=
"Task Development-Define Capacity"
~ Tasks/Week
~ Normal (average) work rate based on normal work week, design staff levels and time per task
|

Time Remaining=
Max(Initial Completion Date-Time,TIME STEP)
~ Week
~ |

Initial Completion Date=
100
~ Week
~ Initial scheduled project completion date
|

Table for Pressure Modifier(
[(0,0)-(1,1)],(0,0),(0.0703364,0.0482456),(0.152905,0.131579),(0.189602,0.254386),(0.229358,0.385965),(0.25,0.5),(0.275229,0.627193),(0.318043,0.776316),(0.351682,0.890351),(0.412844,0.964912),(0.5,1),(0.75,1),(1,1))
~ Dmnl
~ |

Pressure Modifier=
Table for Pressure Modifier(Scheduled Percent total work completed/100)
~ Dmnl

~ Modifier that transfers the schedule pressure from initial to emergent over the course of the project

|

Initial Schedule Pressure=

MIN(1,Initial Desired Work Rate/Normal Work Rate)

~ Dmnl

~ Initial schedule pressure based upon initial required work rate and the normal work rate

|

Realized Schedule Pressure=

((1-Pressure Modifier)*Initial Schedule Pressure)+(Pressure Modifier*Indicated Schedule Pressure)

~ Dmnl

~ Schedule pressure developed as a function of the initial schedule pressure and the emergent pressure during the project

|

Initial Desired Work Rate=

Initial Project Tasks/Initial Completion Date

~ Tasks/Week

~ Initial Scheduled Work Rate based on tasks and initial schedule

|

Rework Defect Fraction per Rework Task=

New Work Defects Fraction*0.25

~ Defects/Tasks

~ Rework tasks are assumed to have lower defect rates as they have already been through the checking process once and are therefore in the process of correcting the defects. There still exists some level of defects though.

|

Time for Sponsor to Approve VO=

12

~ Week

~ Variation orders have to be approved by the project sponsor before they are acted on. This takes a finite time.

|

Rework Capacity from Rework tasks=

Task Rework/Minimum Time per Rework Task

~ Tasks/Week

~ Capacity to complete the rework tasks based on total rework tasks and the minimum time per task (sets an upper bound based on infinite resources i.e reflects the physical constraints of the tasks themselves.)

|

Mimimum Time per Task Approval=
3
~ Week
~ Minimum time in which a task can be approved given infinite resources.
|

Minimum Time per Rework Task=
2
~ Week
~ Minimum time in which a rework task can be completed given infinite resources.
|

Initial Project Tasks=
1000
~ Tasks
~ Initial number of tasks to be completed on the project
|

Minimum Time per Task=
1
~ Week
~ Minimum time in which a task can be completed given infinite resources.
|

Table for Integration Multiplier on Defects(
[(0,0)-(1,2)],(0,0.6),(0.25,0.88),(0.4,1),(0.5,1.05),(0.75,1.1),(1,1.15))
~ Dmnl
~ This look-up function maps the effect that time spent on integration has on the percentage of tasks completed correctly. More time on integration results in fewer defects.
|

Work Capacity from Tasks=
Project Tasks to Do/Minimum Time per Task
~ Tasks/Week
~ Capacity to complete the tasks based on total tasks and the minimum time per task (sets an upper bound based on infinite resources i.e reflects the physical constraints of the tasks themselves.)
|

Work Capacity from Task Approval=
Tasks Completed for Approval/Mimimum Time per Task Approval
~ Tasks/Week

~ Capacity to complete the tasks based on total tasks and the minimum time per task (sets an upper bound based on infinite resources i.e reflects the physical constraints of the tasks themselves.)

|

SW Desire to Hire Full Time Staff=

1

~ Dmnl

~ The switch that allows hiring decisions to be made

|

Normal Work Week=

40

~ hour/Week/engineer

~ Normal hours per week, set at 40 hours

|

Unit Lead Engineer=

1

~ engineer

~ |

Time to Hire Full Time Staff=

12

~ Week

~ Hiring staff takes a finite time as requests are placed with HR, engineers located, transferred or hired into the project.

|

Work Capacity from Full Time Resources=

Normal Task Productivity*Total Available Full Time Eng Hours

~ Tasks/Week

~ The total capacity to do work based on normal productivity and the available engineers.

|

Normal Task Productivity=

0.025

~ Tasks/engineer/hour

~ The productivity for an engineer working on a standard task. Based on completing 1 task per week (40 hours) of week.

|

Total Available Full Time Eng Hours=

Current Work Week*Full Time Staff*Unit Lead Engineer

~ engineer*hour/Week

~ The total available engineering hours is based on the available engineers and the current work week
|

New tasks=
0
~ task/Week
~ |

Fraction of tasks with errors=
0.1
~ Dmnl
~ |

Time to complete tasks=
1
~ Week
~ |

Time to rework the task=
2
~ Week
~ |

Project Staff Additions=
"Project Staffing Constraint(Gap)"/Resource Addition Time
~ Engineers/Week
~ |

Engineers devoted to Project= INTEG (Project Staff Additions-Project Staff reduction,
0)
~ Engineers
~ |

Project Staff reduction=
0
~ Engineers/Week
~ |

"Project Staffing Constraint(Gap)"=
Required Engineers on Project -Engineers devoted to Project
~ Engineers
~ |

Required Engineers on Project=
Initial Required Resources*Input

```
	~	Engineers
	~		|

Initial Required Resources=
	100
	~	Engineers
	~		|

Input=
	1+STEP(Step Height,Step Time)
	~	Dmnl
	~		|

Resource Addition Time=
	8
	~	Week
	~		|

Step Height=
	0.5
	~	Dmnl
	~		|

Step Time=
	40
	~	Week
	~		|

Use of External Contract Resources=
	1
	~	Dmnl
	~		|

********************************************************
	.Control
********************************************************~
		Simulation Control Parameters
	|

FINAL TIME  = 250
	~	Week
	~	The final time for the simulation.
	|

INITIAL TIME  = 0
	~	Week
```

~ The initial time for the simulation.
|

SAVEPER =
TIME STEP
~ Week [0,?]
~ The frequency with which output is stored.
|

TIME STEP = 0.125
~ Week [0,?]
~ The time step for the simulation.
|

Appendix B: Model Simulation Files

```
!This file tests the model for agreed contract price variations, from
!$60/eng*hr to $130/eng*hr. Switches are controlled from the model
!environment.

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>RUNNAME|Margin on 100
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.9
SIMULATE>RUNNAME|Margin on 90
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.8
SIMULATE>RUNNAME|Margin on 80
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.7
SIMULATE>RUNNAME|Margin on 70
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>RUNNAME|Margin on 60
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.1
SIMULATE>RUNNAME|Margin on 110
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.2
SIMULATE>RUNNAME|Margin on 120
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>RUNNAME|Margin on 130
MENU>RUN|o
```

```
!Sponsors Paradise: This file tests the model for agreed contract price
!variations, from $60/eng*hr to $130/eng*hr. The agreed price has no
!(direct)impact on the number of VOs submitted, the initial staff
!numbers, or on-going hiring


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 100
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.9
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 90
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.8
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 80
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.7
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 70
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 60
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
```

```
SIMULATE>SETVAL|SW Price impact on Initial Staff=0

SIMULATE>RUNNAME|Margin on 110
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.2
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 120
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=0
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 130
MENU>RUN|o



!Variation Orders are a Reality: This file tests the model for agreed
!contract price variations, from $60/eng*hr to $130/eng*hr. The agreed
!price impacts the number of VOs submitted, but does not effect the
!initial staff numbers, or on-going hiring


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 100
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.9
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 90
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.8
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 80
MENU>RUN|o
```

```
SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.7
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 70
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 60
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 110
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.2
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 120
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=0
SIMULATE>RUNNAME|Margin on 130
MENU>RUN|o

!A Smaller team will get it done: This file tests the model for agreed
!contract price variations, from $60/eng*hr !to $130/eng*hr. The agreed
!price impacts the number of VOs submitted and the initial staff
!numbers, but does not effect on-going hiring


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
```

```
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 100
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.9
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 90
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.8
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 80
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.7
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 70
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 60
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 110
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.2
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 120
MENU>RUN|o
```

```
SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=0
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 130
MENU>RUN|o


!People Cost money: This file tests the model for agreed contract price
!variations, from $60/eng*hr !to $130/eng*hr. The agreed price impacts
!the number of VOs submitted, the initial staff numbers and the on-
!going hiring.


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 100
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.9
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 90
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.8
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 80
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.7
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 70
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
```

```
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 60
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.1
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 110
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.2
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 120
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|SW Switch for Profit effect on VO submitted=1
SIMULATE>SETVAL|SW Switch for Profit Multiplier on Hiring=1
SIMULATE>SETVAL|SW Price impact on Initial Staff=1
SIMULATE>RUNNAME|Margin on 130
MENU>RUN|o

!This file tests the model for sensitivity to variations in the VO mark
!up rate. Three agreed contract prices are simulated and each is then
!tested at different mark up rates.

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Variation Order Mark Up=1.1
SIMULATE>RUNNAME|Margin on 60, Mark Up 1.1
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Variation Order Mark Up=1.25
SIMULATE>RUNNAME|Margin on 60, Mark Up 1.25
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Variation Order Mark Up=1.4
SIMULATE>RUNNAME|Margin on 60, Mark Up 1.4
MENU>RUN|o
```

```
SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Variation Order Mark Up=1.1
SIMULATE>RUNNAME|Margin on 100, Mark Up 1.1
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Variation Order Mark Up=1.25
SIMULATE>RUNNAME|Margin on 100, Mark Up 1.25
MENU>RUN|o


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Variation Order Mark Up=1.4
SIMULATE>RUNNAME|Margin on 100, Mark Up 1.4
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Variation Order Mark Up=1.1
SIMULATE>RUNNAME|Margin on 130, Mark Up 1.1
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Variation Order Mark Up=1.25
SIMULATE>RUNNAME|Margin on 130, Mark Up 1.25
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Variation Order Mark Up=1.4
SIMULATE>RUNNAME|Margin on 130, Mark Up 1.4
MENU>RUN|o



!This file tests the model sensitivity to VO Approval Time.

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Time for Sponsor to Approve VO=16
SIMULATE>RUNNAME|Margin 60 Time 16wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
```

```
SIMULATE>SETVAL|Time for Sponsor to Approve VO=12
SIMULATE>RUNNAME|Margin 60 Time 12wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Time for Sponsor to Approve VO=8
SIMULATE>RUNNAME|Margin 60 Time 8wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Time for Sponsor to Approve VO=4
SIMULATE>RUNNAME|Margin 60 Time 4wks
MENU>RUN|o


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Time for Sponsor to Approve VO=16
SIMULATE>RUNNAME|Margin 100 Time 16wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Time for Sponsor to Approve VO=12
SIMULATE>RUNNAME|Margin 100 Time 12wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Time for Sponsor to Approve VO=8
SIMULATE>RUNNAME|Margin 100 Time 8wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Time for Sponsor to Approve VO=4
SIMULATE>RUNNAME|Margin 100 Time 4wks
MENU>RUN|o


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Time for Sponsor to Approve VO=16
SIMULATE>RUNNAME|Margin 130 Time 16wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
```

```
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Time for Sponsor to Approve VO=12
SIMULATE>RUNNAME|Margin 130 Time 12wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Time for Sponsor to Approve VO=8
SIMULATE>RUNNAME|Margin 130 Time 8wks
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Time for Sponsor to Approve VO=4
SIMULATE>RUNNAME|Margin 130 Time 4wks
MENU>RUN|o


!Ideal integration Time - varied from 0.1 to 0.5. This simulation tests
!the model sensitivity to variation in the ideal fraction time spent on
!integration. Can be thought of as a proxy for system complexity.

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.1
SIMULATE>RUNNAME|Margin 60 Int Fraction 0.1
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.2
SIMULATE>RUNNAME|Margin 60 Int Fraction 0.2
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.3
SIMULATE>RUNNAME|Margin 60 Int Fraction 0.3
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.4
SIMULATE>RUNNAME|Margin 60 Int Fraction 0.4
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=0.6
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.5
SIMULATE>RUNNAME|Margin 60 Int Fraction 0.5
```

```
MENU>RUN|o


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.1
SIMULATE>RUNNAME|Margin 100 Int Fraction 0.1
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.2
SIMULATE>RUNNAME|Margin 100 Int Fraction 0.2
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.3
SIMULATE>RUNNAME|Margin 100 Int Fraction 0.3
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.4
SIMULATE>RUNNAME|Margin 100 Int Fraction 0.4
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.5
SIMULATE>RUNNAME|Margin 100 Int Fraction 0.5
MENU>RUN|o


SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.1
SIMULATE>RUNNAME|Margin 130 Int Fraction 0.1
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.2
SIMULATE>RUNNAME|Margin 130 Int Fraction 0.2
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.3
```

```
SIMULATE>RUNNAME|Margin 130 Int Fraction 0.3
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.4
SIMULATE>RUNNAME|Margin 130 Int Fraction 0.4
MENU>RUN|o

SIMULATE>SETVAL|Initial Project Tasks=1000
SIMULATE>SETVAL|Initial Completion Date=100
SIMULATE>SETVAL|Margin Accepted on Contract=1.3
SIMULATE>SETVAL|Ideal Fraction Time on Integration=0.5
SIMULATE>RUNNAME|Margin 130 Int Fraction 0.5
MENU>RUN|o
```

Appendix C: Model Optimization Results

Model Optimization: "Project Sponsor Cost"

Sorted Parameter Sensitivities
Parameters are changed by +- 50%, if 0 by +- 0.5

PARAMETER	-0.5	0.5
Normal Task Productivity=0.025	-2.46E+09	9.46E+08
Initial Project Tasks=1000	2.14E+09	-2.14E+09
Preferred Return Hourly rate=100	2.14E+09	-2.14E+09
Typical New Task Correct Fraction=0.85	-1.90E+09	1.90E+09
SW Desire to generate VO=1	1.24E+09	-1.57E+09
Margin Accepted on Contract=1	1.39E+09	-9.61E+08
SW Defect Switch=1	1.01E+09	-1.13E+09
VO Task Productivity=0.025	-1.06E+09	4.49E+08
SW TCA Sched Press=0	-1.05E+09	9.63E+08
Desired Time to Generate VO Task=2	-1.02E+09	4.00E+08
SW Switch for RI effect on VO Submitted=1	8.73E+08	8.73E+08
Benchmarked Percentage of Rework Tasks that lead to VO=0.3	7.48E+08	-6.55E+08
Time for Sponsor to Approve VO=12	6.97E+08	-5.83E+08
SW Staff reduction based on Scale and synergy expectations=1	3.34E+07	6.62E+08
SW Project Profit Switch=1	-6.41E+08	4.80E+08
Ideal Fraction Time on Integration=0.4	3.85E+08	-5.83E+08
Variation Order Mark Up=1.5	4.49E+08	-5.76E+08
SW Switch for Profit effect on VO submitted=1	-4.82E+08	-4.82E+08
defect to task ratio=1	-1.19E+08	4.02E+08
SW VO Ratio Impact on RI=1	3.42E+08	3.42E+08
Initial Completion Date=100	-3.04E+08	2.27E+08
Normal Approval Task Productivity=0.1	-2.89E+08	1.17E+08
Schedule Delay=6	-1.32E+08	1.95E+08
SW Delay Penalty Switch=0	1.93E+08	-1.93E+08
SW Desire to Track RI=1	1.77E+08	-6.03E+07
Estimated Initial Defect Fraction=0.15	1.45E+08	-1.54E+08
Time to Adj Completion Rate=16	-1.29E+08	1.16E+08
Benchmarked Defect Fraction=0.15	-1.20E+08	1.12E+08
Time to Update RI Decrease=8	-9.33E+07	9.17E+07
Initial Overhead Engineering fraction=0.1	7.79E+07	-7.21E+07
Initial RI=1	-6.28E+07	1.84E+07
Percent of VOs requiring New Tasks=0.5	5.32E+07	-5.19E+07
Time to Hire Full Time Staff=12	2.06E+07	-1.07E+07
SW Desire to update Schedule Pressure=1	2.04E+07	-6.53E+06
Time to Update Desired Staff=8	1.69E+07	-9.83E+06
SW Desire to Hire Full Time Staff=1	-1.45E+07	1.23E+07
Time to Average the Schedule Pressure=4	-8.92E+06	9.19E+06
Mimimum Time per Task Approval=3	1.27E+06	5.83E+06
Minimum Time per Rework Task=2	4.23E+06	-1.90E+06
SW Switch for Profit Multiplier on Hiring=1	4.13E+06	4.13E+06
Time to Update RI Increase=16	2.37E+06	-3.03E+06
Minimum Time per Task=1	-10820.3	-695541
Break Even Hourly Rate=70	0	-855.25

Unit Lead Engineer=1	0	-221.625
Normal Work Week=40	0	-167.75
Use of External Contract Resources=1	0	0
Time to rework the task=2	0	0
Time to complete tasks=1	0	0
SW Price impact on Initial Staff=1	0	0
Step Time=40	0	0
Step Height=0.5	0	0
Resource Addition Time=8	0	0
Project Staff reduction=0	0	0
New tasks=0	0	0
Initial Required Resources=100	0	0
Fraction of tasks with errors=0.1	0	0
Delay Cost=200000	0	0

Model Optimization: "Variation Order Generation"

Sorted Parameter Sensitivities
Parameters are changed by +- 50%, if 0 by +- 0.5

PARAMETER	-0.5	0.5
Typical New Task Correct Fraction=0.85	230.661	-1633.71
SW Desire to generate VO=1	-310.569	262.365
SW Switch for RI effect on VO Submitted=1	-273.675	-273.675
SW Defect Switch=1	-235.396	193.808
Initial Project Tasks=1000	-211.358	211.358
Benchmarked Percentage of Rework Tasks that lead to VO=0.3	-192.217	126.607
Margin Accepted on Contract=0.6	-182.043	-119.571
SW Staff reduction based on Scale and synergy expectations=1	-155.689	-41.368
SW Switch for Profit effect on VO submitted=1	139.943	139.943
SW TCA Sched Press=0	11.0507	-128.731
SW Project Profit Switch=1	58.7299	-88.1255
SW VO Ratio Impact on RI=1	-82.8742	-82.8742
Initial Completion Date=100	-64.4412	-72.9238
Desired Time to Generate VO Task=2	-70.9223	36.0084
VO Task Productivity=0.025	-70.6006	37.0826
SW Price impact on Initial Staff=1	-65.5789	-65.5789
Variation Order Mark Up=1.5	64.4295	-42.2493
Time for Sponsor to Approve VO=12	58.2503	-29.5282
Ideal Fraction Time on Integration=0.4	-22.0112	-55.0032
defect to task ratio=1	-47.1073	-52.7242
Normal Task Productivity=0.025	40.136	-52.5669
Percent of VOs requiring New Tasks=0.5	-31.9855	31.1586
SW Desire to Track RI=1	-22.6819	5.77131
Time to Adj Completion Rate=16	16.92	-15.8786
Normal Approval Task Productivity=0.1	-15.54	3.11434
SW Switch for Profit Multiplier on Hiring=1	-12.6147	-12.6147
Time to Update RI Decrease=8	10.1783	-11.8657
Benchmarked Defect Fraction=0.15	6.87035	-11.0281
Schedule Delay=6	5.37613	-7.66598
Estimated Initial Defect Fraction=0.15	3.1908	-6.77469
Initial RI=1	5.78076	-1.79332
SW Desire to update Schedule Pressure=1	-4.48593	1.70088
Initial Overhead Engineering fraction=0.1	2.64889	-3.02532
Time to Average the Schedule Pressure=4	2.59912	-2.34907
Time to Update RI Increase=16	-1.99793	1.56283
Time to Hire Full Time Staff=12	-1.93754	0.745748
Time to Update Desired Staff=8	-1.45486	0.793763
SW Desire to Hire Full Time Staff=1	0.771964	-1.11971
Mimimum Time per Task Approval=3	-0.114434	0.0819493
Minimum Time per Rework Task=2	-0.0689198	0.111334

Minimum Time per Task=1	8.53E-06	-0.0218723
Break Even Hourly Rate=70	0	0.0002982 83
Preferred Return Hourly rate=100	0	0.0001896 06
Unit Lead Engineer=1	0	5.02E-05
Normal Work Week=40	0	2.62E-05
Use of External Contract Resources=1	0	0
Time to rework the task=2	0	0
Time to complete tasks=1	0	0
SW Delay Penalty Switch=0	0	0
Step Time=40	0	0
Step Height=0.5	0	0
Resource Addition Time=8	0	0
Project Staff reduction=0	0	0
New tasks=0	0	0
Initial Required Resources=100	0	0
Fraction of tasks with errors=0.1	0	0
Delay Cost=200000	0	0

Model Optimization: "Expected Variation Order Revenue"

Sorted Parameter Sensitivities
Parameters are changed by +- 50%, if 0 by +- 0.5

PARAMETER	-0.5	0.5
Typical New Task Correct Fraction=0.85	6.71E+08	-2.14E+09
VO Task Productivity=0.025	1.44E+09	-5.77E+08
SW Desire to generate VO=1	-1.24E+09	6.97E+08
Margin Accepted on Contract=0.6	-1.09E+09	-8.32E+07
SW Switch for RI effect on VO Submitted=1	-1.04E+09	-1.04E+09
SW Staff reduction based on Scale and synergy expectations=1	-9.13E+08	2.01E+08
Preferred Return Hourly rate=100	-9.10E+08	9.10E+08
Initial Project Tasks=1000	-9.10E+08	9.10E+08
Variation Order Mark Up=1.5	-8.85E+08	7.56E+08
SW Defect Switch=1	-8.51E+08	4.98E+08
Desired Time to Generate VO Task=2	8.09E+08	-4.20E+08
SW TCA Sched Press=0	-3.85E+08	-8.03E+08
Initial Completion Date=100	7.67E+08	-5.51E+08
Benchmarked Percentage of Rework Tasks that lead to VO=0.3	-6.91E+08	2.63E+08
Time for Sponsor to Approve VO=12	-6.52E+08	4.01E+08
defect to task ratio=1	-4.63E+08	2.79E+07
SW Project Profit Switch=1	-3.35E+08	-2.05E+08
Ideal Fraction Time on Integration=0.4	-3.14E+08	1.49E+08
SW VO Ratio Impact on RI=1	-2.04E+08	-2.04E+08
SW Switch for Profit effect on VO submitted=1	1.73E+08	1.73E+08
Normal Approval Task Productivity=0.1	1.55E+08	-8.63E+07
SW Price impact on Initial Staff=1	1.48E+08	1.48E+08
Time to Adj Completion Rate=16	1.30E+08	-1.17E+08
Normal Task Productivity=0.025	-1.16E+08	-3.50E+07
SW Desire to Track RI=1	-1.10E+08	3.43E+07
Estimated Initial Defect Fraction=0.15	-1.07E+08	9.30E+07
SW Switch for Profit Multiplier on Hiring=1	1.06E+08	1.06E+08
SW Desire to Hire Full Time Staff=1	-7.10E+07	2.29E+07
Initial Overhead Engineering fraction=0.1	-5.73E+07	4.85E+07
Time to Update RI Decrease=8	5.27E+07	-5.60E+07
Initial RI=1	4.94E+07	-1.45E+07
Schedule Delay=6	3.06E+07	-4.82E+07
SW Desire to update Schedule Pressure=1	-4.24E+07	1.63E+07
Time to Hire Full Time Staff=12	3.39E+07	-3.55E+07
Benchmarked Defect Fraction=0.15	2.51E+07	-3.49E+07
Time to Average the Schedule Pressure=4	2.50E+07	-2.23E+07
Time to Update Desired Staff=8	2.30E+07	-2.41E+07
Percent of VOs requiring New Tasks=0.5	-1.71E+07	4.41E+06
Time to Update RI Increase=16	-2.64E+06	1.91E+06
Mimimum Time per Task Approval=3	463973	-2.39E+06
Minimum Time per Rework Task=2	-255717	-168663
Minimum Time per Task=1	0	-12520.8

Break Even Hourly Rate=70	0	-384.454
Unit Lead Engineer=1	0	-170.126
Normal Work Week=40	0	-170.067
Use of External Contract Resources=1	0	0
Time to rework the task=2	0	0
Time to complete tasks=1	0	0
SW Delay Penalty Switch=0	0	0
Step Time=40	0	0
Step Height=0.5	0	0
Resource Addition Time=8	0	0
Project Staff reduction=0	0	0
New tasks=0	0	0
Initial Required Resources=100	0	0
Fraction of tasks with errors=0.1	0	0
Delay Cost=200000	0	0

Model Optimization: "Variation Orders Submitted"

Sorted Parameter Sensitivities
Parameters are changed by +- 50%, if 0 by +- 0.5

PARAMETER	-0.5	0.5
Typical New Task Correct Fraction=0.85	4749.77	-156430
SW Desire to generate VO=1	-2711.98	4164.19
SW TCA Sched Press=0	2873.32	-1869.38
SW Defect Switch=1	-2028.5	2764.44
SW Project Profit Switch=1	2324.61	-1013.53
SW Switch for RI effect on VO Submitted=1	-1812.66	-1812.66
Initial Project Tasks=1000	-1784.42	1784.43
Ideal Fraction Time on Integration=0.4	852.138	-1626.32
Time for Sponsor to Approve VO=12	-1585.65	1284.63
Benchmarked Percentage of Rework Tasks that lead to VO=0.3	-1532.61	1520.3
SW Staff reduction based on Scale and synergy expectations=1	809.686	-1494.97
defect to task ratio=1	968.317	-1261.34
Margin Accepted on Contract=1	1211.92	-816.002
SW Switch for Profit effect on VO submitted=1	1203.79	1203.79
Normal Task Productivity=0.025	802.482	-541.404
SW VO Ratio Impact on RI=1	-775.751	-775.751
Initial Completion Date=100	-737.8	-71.7887
Normal Approval Task Productivity=0.1	-630.643	182.416
VO Task Productivity=0.025	-570.49	264.144
Desired Time to Generate VO Task=2	-395.315	166.18
SW Desire to Track RI=1	-361.621	119.614
Schedule Delay=6	234.605	-355.558
Variation Order Mark Up=1.5	264.144	-318.428
Estimated Initial Defect Fraction=0.15	217.683	-291.163
Benchmarked Defect Fraction=0.15	260.804	-250.226
Time to Adj Completion Rate=16	200.859	-200.697
Time to Update RI Decrease=8	188.07	-191.808
Percent of VOs requiring New Tasks=0.5	-139.202	155.608
Initial Overhead Engineering fraction=0.1	126.255	-138.184
Initial RI=1	123.708	-36.7968
Mimimum Time per Task Approval=3	116.067	-106.37
Time to Hire Full Time Staff=12	-63.6652	36.2389
SW Desire to Hire Full Time Staff=1	61.05	-37.4666
Time to Update Desired Staff=8	-46.4544	33.2808
Minimum Time per Rework Task=2	32.3013	-44.2613
SW Desire to update Schedule Pressure=1	-22.4014	3.00442
SW Switch for Profit Multiplier on Hiring=1	-20.2256	-20.2256
Time to Average the Schedule Pressure=4	5.77388	-12.5488
Time to Update RI Increase=16	-9.36125	1.37604
Minimum Time per Task=1	0.243544	-5.87355
Preferred Return Hourly rate=100	0	0.007315
Break Even Hourly Rate=70	0	0.003632

Unit Lead Engineer=1	0	0.002453
Normal Work Week=40	0	0.001728
Use of External Contract Resources=1	0	0
Time to rework the task=2	0	0
Time to complete tasks=1	0	0
SW Price impact on Initial Staff=1	0	0
SW Delay Penalty Switch=0	0	0
Step Time=40	0	0
Step Height=0.5	0	0
Resource Addition Time=8	0	0
Project Staff reduction=0	0	0
New tasks=0	0	0
Initial Required Resources=100	0	0
Fraction of tasks with errors=0.1	0	0
Delay Cost=200000	0	0