The Micro-foundations of Alignment among Sponsors and Contractors on Large Engineering Projects.

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SUBMITTED TO THE ENGINEERING SYSTEMS DIVISION IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN ENGINEERING SYSTEMS
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JULY 2006
[September 2006]

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Submitted to the Engineering Systems Division on July 24, 2006 in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering Systems

Abstract

Large engineering projects design, engineer and construct much of the world's energy, transportation and defense infrastructure. These large scale engineering endeavors are highly visible, have long lasting impacts and are of major economic significance. Yet despite their importance they frequently suffer from cost overruns and long delays and deliver systems with operational shortcomings.

A contributing factor to the challenge of large projects is that the project enterprise is created by separate firms being brought together by the project sponsor, typically via formal contracts. Success requires multiple firms with hundreds (possibly thousands) of engineers working together to efficiently create complex product systems within an environment of high uncertainty. In an attempt to improve project outcomes, sponsors often endeavor to create "alignment" between themselves and their key contractors. In practice, alignment has proved difficult to create and to sustain. This research explores the policies and actions taken by firms that give rise to alignment.

The large engineering projects studied for this research were offshore oil and gas field developments. A grounded theory method, supplemented by formal dynamic model building, was used to investigate the causal mechanisms that support, or inhibit, the generation of alignment. The research revealed that alignment is founded on the collective understanding of the project, incorporating the firm's separate interests, and inter-firm trust. Furthermore the two antecedents of alignment act together to form a self-enforcing alignment mechanism. Six factors (system architecture, organizational design, contract design, risk, metrics and incentives) were identified that establish the inter-firm interactions through which collective understanding and inter-firm trust are created. These findings are organized into a framework that guides policy selection with a view to enabling the generation, and sustainment, of alignment.

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Acknowledgements

Like many students before me, researching and writing this thesis taught me much about my area of interest and especially about myself. I'd like to pause and take a few moments to thank all of those who shared this journey with me.

From the day Debbie Nightingale agreed to be the chair of my thesis committee her enthusiasm for my ideas was unwavering. I thank her for her energy and support, especially during those days when, (perhaps only evident to myself), I questioned the value of my work. I especially appreciate her efforts in shepherding me through the doctoral program and keeping me focused on my thesis. Without her sage advice I would have most likely pursued too many diversions and lost sight of the "prize".

Don Lessard provided thoughtful observations and encouragement in equal measure. Conversations with Don frequently left me with both new insights and new challenges to master. I was constantly amazed by his ability to reframe my work, expose any instances of awkward reasoning, and at the same time excite in me a desire to think more deeply about the research.

Nelson Repenning was my intellectual guide and mentor from my first day at MIT. He provided the support and guidance I needed to shape and refine my ideas, as well as the encouragement to pursue them. He was a wonderful advisor; had it not been for him it is doubtful that I would have pursued a Ph.D. To me, he is a model of the ideal academic: intellectually curious, analytically rigorous, and grounded in the challenges and context of the "real world." He is also a superb teacher with time, patience and encouragement for his students.

It is also important to acknowledge the amazing support I received from Judy Wagner. Without her tireless efforts I would not have been blessed with the access to her organization that I enjoyed. I must also say a thank you to Steve Garner. Taking a chance on an inexperienced graduate student he offered me a desk and an opportunity to go "behind the scenes".

My journey through this thesis would not have been possible without the encouragement and support of my fellow graduate students and friends. My thanks therefore extend to those who shared many a drink and many a laugh with me at the Muddy; you kept me sane and inspired. Here's cheers to Alexis Stanke, Kate Steel, Travis Frank, Dave Danielson, Josh Syken and Nicki Tolliday.

My parents, Ingrid and Geoff, have always encouraged me to pursue my ambitions. The example of their lives enabled me to believe that I could accept any challenge and that with hard work and dedication I could achieve my dreams. My brother Matt and my sister-in-law Suzie were always willing to listen to my fears, calm my doubts and celebrate my small victories along the way. Finally, and especially, I would like to thank Tadzia. Without her continual and unselfish support, the example of her own amazing

achievements, and her understanding in the face of my many late nights of work, none of this would have been possible. I'd like to finish by dedicating this thesis to my Grandparents, Albi and Irene Kaminickas. Throughout my life they have been an inspiration to me.

For Irene Kaminickas
1920 - 2006

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1.0 Introduction

1.1 Problem Statement

A senior project manager once asked me: “How do we get alignment with our contractors?” The idea of alignment is a simple one, but enormously complex in execution. It can be conceived of as a principal-agent problem, incorporating all the challenges of information asymmetry and observability and the consequent risk of opportunism. However for large engineering projects the “principal” is often a multi-national corporation or a national government, and the “agent”, or more frequently agents, are likewise a set of multi-national engineering and construction firms. How, on a multi-year, multi-billion dollar engineering project do we create the environment where the firms act together to achieve the outcome desired by the project sponsor at the same time as delivering the rewards the engineering firms seek? This is not an easy problem and one I wrestled with both in my career as a practitioner and as a researcher. My research question is in two parts:

1. What constitutes alignment amongst firms executing large engineering projects?
2. What policies or actions facilitate the generation of alignment?

1.2 Motivation

My research was motivated by own experiences as an engineer working for contractors on large engineering projects; specifically offshore oil and gas developments. I was frequently confronted with situations in which disputes amongst the firms working on a project became an impediment to the delivery of the final product; relationships were often fractious. Some of this I could explain in terms of the complexity of the engineering problems to be solved and disagreements about which solution was optimal. However it appeared to me that a contributing factor was the way in which firms were organized. In particular, the way in which the individual firms were being rewarded for providing their services appeared to influence their ability or willingness to devote resources, time and attention to certain aspects of the project.

Initially I investigated two distinct types of contracts used in the oil and gas industry with the aim of understanding how, and by what mechanisms, their respective explicit and implicit reward systems shaped firm interactions. The first was the “lump-sum” or “fixed price” contract which features an agreed contract price along with mechanisms for “change orders” (contractor charges for work not included in the original scope of work). The second was an innovative contract arrangement, which created shared incentives for contractors to manage costs and limit change orders, that became popular in the 1990s before fading from prominence; the “alliance” contract.

As I set out to understand these two different contract regimes, I anticipated that my interviews with managers from project sponsors and contractors would suggest a focus on incentives as the appropriate mechanism for generating alignment between firms. In particular, I expected that contractors would place a great deal of emphasis on what contract types, and especially what incentive structures, work best in generating effective interactions between themselves and the project sponsor. However, counter to my expectation and intuition, my research revealed that formal incentives were only one element shaping critical inter-firm interactions on a project, and seemingly not the most important one. As the Vice President of Engineering for one contractor put it:

> "The most important thing is the relationship, incentives can't guarantee that"

Based upon interviews, field observations, secondary data, literature from a number of distinct academic disciplines and formal mathematical models, I have developed a grounded theory of alignment amongst firms engaged on large engineering projects. This theory includes aspects of the formal incentive arrangements that I had assumed to be central, but adds equally critical considerations of system architecture, allocation of risk, metrics and organizational design. The theory is then captured in a set of frameworks aimed at assisting project practitioners with understanding and designing the mechanisms that generate alignment.

1.3 What is Alignment?

The notion of alignment appears in a multitude of academic papers across a number of disciplines. Frequently however it is not explicitly defined and the reader is left to apply a natural language definition of alignment. The MSN Encarta online dictionary offers the following definition of alignment:

> "The correct position or positioning of different components with respect to each other or something else, so that they perform properly."[1]

This definition captures an important aspect of alignment that is often assumed but rarely made explicit. That alignment not only involves the way in which elements are arranged relative to each other, but also how the system of aligned components performs. The assumption motivating my research is that achieving alignment will assist in delivering superior (project) performance.

The notion of alignment delivering proper performance is found in a number of fields. Information technology and information systems literature deals with the challenge of alignment extensively (for a review see Avison, Jones, et al 2004). In this environment the literature suggests that "firms cannot be competitive or successful if their business and information technology (IT)/information systems (IS) strategies are not aligned"[2]. Organizational alignment broadens the idea away from an IT/IS focus to one of alignment between business strategy and organizational design (Porter 1987, 1996), or alternatively to the question of alignment between an organization and its environment (Lawrence and Lorsch 1967, Powell 1992). In the realm of engineering projects Griffith and Gibson (2001) offer the following definition:

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[1] http://encarta.msn.com/dictionary_/Alignment.html
[2] Avison, Jones, et al 2004

> "Alignment can be defined as the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives".[3]

A limitation of this definition is that it doesn't explicitly acknowledge that the project participants may have interests external to the project objectives. It is creating alignment in this environment of potentially divergent interests that is most challenging. The definition offered by the MIT Working Group on Alignment addresses this shortcoming. Alignment is defined as:

> "Formal and informal patterns of interaction within and across inter-dependent stakeholders that serve to advance the separate and the collective interests of these stakeholders."[4]

My research highlights the patterns of interaction that constitute alignment, and investigates the behaviors, policies and actions that support their generation.

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[3] Griffith A, F., Gibson G, E., 2001, pp 69.
[4] Moses J., Cutcher-Gershenfeld J., 2005.

1.4 Why is (understanding) Alignment Important?

Understanding alignment amongst firms is important from pragmatic as well as academic perspectives. I will begin this section by highlighting the pragmatic importance of alignment using two examples with a focus on business activities.

While many small projects are executed by teams that exist within a single firm, large engineering projects (LEPs) typically involve a number of firms being brought together by the project sponsor through the use of contracts. Examples of LEPs are found in industries such as aerospace/defense (satellites and weapons systems) and energy (offshore oil and gas platforms, nuclear power plants). Successful LEPs require multiple firms with hundreds (possibly thousands) of engineers to work together to create extremely complex product systems. A set of activities organized sequentially and managed by one firm, in the manner of traditional small scale product development, is not practical in this environment, thus work is carried out concurrently amongst tightly coupled organizations.

As stated by Miller and Lessard (2000)

> "Large engineering projects (LEPs), such as airports, urban-transport systems, oil fields, and power systems, constitute one of the most important business sectors in the world" and "they transform the physical landscape and change the quality of human life".

However, despite LEPs visibility, scale, long-lasting impact and economic significance, they frequently suffer from poor performance (Miller & Lessard 2000, Flyvbjerg 2003, Williams 2005). Miller and Lessard reported on the International Program in the Management of Engineering and Construction (IMEC) study of 60 LEPs (undertaken from the early 1980s to the late 1990s with an average cost of close to $1 billion). The study revealed that "close to 40 percent of them performed very badly" and "18.1 percent displayed extensive cost overruns and 26.7 percent had long schedule overruns". Understanding the mechanisms that generate inter-firm alignment offers the potential of enhanced project performance.

Enterprises that span multiple firm boundaries are not limited to the environment of LEPs. *The Economist* declared in 2005 that: "There is no doubt that firms today use outside suppliers (some of them overseas) to do many of the things they once did themselves. These range from running call centres supplying customer services to payroll processing, software engineering and even research and development"[5]. In a separate article the Economist identified declining shipping costs, abundant and cheap telecommunications bandwidth and the internet as drivers for this phenomenon, often referred to as outsourcing, and declared that the reorganization of work is likely to advance rapidly.[6]

However, the shift to locating activities essential to the delivery of a firm's goals to outside of the firm itself is not without risk. Again from the *Economist*: "A recent survey

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[5] The Economist, Jun 30th 2005, "Getting the measure of it"

[6] The Economist, Nov 11th 2004, "A world of work"

by Bain & Co, a firm of consultants, found that a hefty 82% of large firms in Europe, Asia and North America are today using outsourcing firms, and 51% are outsourcing offshore. But almost half say that their outsourcing does not meet their expectations."[7] Thus, understanding the mechanisms that shape inter-organizational relationships may help inform better management decision making, and deliver improved outsourcing outcomes.

Notwithstanding the imperatives of global business, I argue that understanding alignment is a useful academic pursuit. Sosa, et al 2004 state that "the explicit link between product architecture and organizational structure has been largely ignored"[8] and cite Krishnan and Ulrich 2001 and Sosa et al 2003 for evidence. In their paper Sosa et al begin to address this perceived gap and in doing so conclude by nominating the following pressing question for researchers to pursue:

> "What architectural and organizational mechanisms influence team's cognitive capabilities across boundaries?"

This question was motivated by the papers conclusion that "teams may fail to perceive the actual criticality of their cross-boundary design interfaces"[9]. Given the evidence to support this conclusion in an environment in which the teams all belong to the one organization (in this case Pratt & Whitney), it is likely to be doubly true for LEPs where the "teams" are in fact legally distinct and frequently competing firms. The question

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[7] *The Economist*, March 3rd 2005, "Time to bring it back home"
[8] Sosa M, E., Eppinger S, D., Rowles C, M., 2004, pp 1676
[9] Sosa M, E., Eppinger S, D., Rowles C, M., 2004, pp 1688

posed above by Sosa et al (2004) resides at the heart of the challenge of understanding alignment. We need to understand how independent firms can generate collaborative knowledge building and decision making mechanisms across projects; how, in the words of Sosa et al, do we develop team's cognitive capabilities across boundaries?

Finally, understanding alignment is important to the academic mission of Engineering Systems. A particular feature of the Engineering Systems approach is its holism. It "emphasizes the behavior or structure of the whole in contrast to its parts" (Moses 2004). The engineering systems monograph, presented at the 2004 Engineering Systems Symposium, outlined the key issues facing the study of large-scale, complex, technologically enabled systems. Enterprise issues were identified as one of the foundational issues for the field of Engineering Systems; in particular "the field... ...is interested in the relationship between the organization of enterprises and their technical systems."[10] Project based enterprises, which are the subject of this research, clearly exhibit strong "relationships" between the project organization and the physical artifact they develop. A critical aspect of the alignment challenge revolves around this interdependence between technology and the organization.

1.5 An Interdisciplinary Approach

The study of project-based organizations, and the drivers of project performance in general, has generated a rich literature that cuts across a number of academic disciplines

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[10] Moses J., 2004

including system architecture, organization theory, economics, product development and system dynamics. As a result our understanding of LEPs is enhanced by drawing upon these diverse fields.

1.5.1 An Integrated Approach: Foundational Literatures

At the heart of a large engineering project is the physical system itself; the artifact that is being developed. The firms are assembled to deliver specific elements of the product system. These elements may be the design of a subsystem, the fabrication of a subsystem or the integration of multiple subsystems. In each case the relationship between these system elements partially defines the relationships between the firms involved. The nature of the system architecture being developed is therefore critical to understanding how the firms interact (Rechtin and Maier 2000, Novak and Eppinger 2001). For example, large offshore oil and gas facilities can be characterized as integral architectures under a number of definitions (Ulrich and Eppinger 2000, Sosa, Eppinger and Rowles 2000, Whitney 2004) with consequent implications for their development.

The relevant product development literature notes that the integral nature of a product system has important implications for its development process. As Novak and Eppinger (2001) point out "the more interconnected are the parts of a system, the more difficult it is to coordinate development"[11]. 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 respect to improved project

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[11] Novak C., Eppinger S, D., 2001, pp 190.

performance, particularly "in relationships between individuals or engineering groups where the output of one is the input for the other"[12]. As stated by Eppinger (1997); "To assure that the entire system works together, the many sub-system development teams must work together".[13]

The product development and the product management literatures broadly agree that projects can be thought of as sets of decision making activities (Kerzner 1992, Ulrich and Eppinger 2000, Blanchard and Fabrycky 2000, Pich, Loch and De Meyer 2002) that draw upon individual and organizational knowledge and frequently create knew knowledge (Cleland 1999, Ulrich and Eppinger 2000). I therefore draw upon literature that considers how individuals and groups of individuals within firms make decisions (March and Simon 1958, Simon 1959, 1979, Perrow 1986). Large engineering projects span boundaries within and across firms, and as a result decision making across boundaries needs to be incorporated (Huber and McDaniel 1986, Sterman 1989, Huber 1990, Sosa et al 2004).

Decision making in organizations is supported by individual and organizational knowledge (March and Simon 1958) and this remains true for projects (Pich, Loch and De Meyer 2002). Knowledge creation within firms (Nonoka 1994, Grant 1996) and across firm boundaries (Dyer and Nobeoka 2000, Hansen 2002, Carlile 2002, 2004) by individuals and teams of individuals is considered.

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[12] Wheelwright S, C., Clark K, B., 1992, pp 175.

[13] Eppinger S, D., 1997, pp 199.

Team processes are critical to project outcomes (Cleland 1999). Group cohesiveness has been described as a 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."[14] 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."[15] Research on trust has therefore played an important role in my research, from calculative views of trust (Williamson 1993) to relational perspectives (Mayer et al 1995, McAllister 1995). Trust across organizational boundaries has been especially important to consider (Dyer 1997, Zaheer et al 1998, Carson et al 2003). The research into high reliability organizations has provided a contextual analogue for my investigation of project alignment. We find in this context that trust, reciprocity, and repeated structured interaction form the foundations of robust team dynamics (Weick 1993, LaPorte and Consolini 1991).

A project is shaped not just by the team process, but by the organizational and contractual arrangements that exist between firms and indeed by the arrangement of firm boundaries. Thus any consideration of how firms interact on a project requires at least some consideration of how firms arrange themselves with respect to their boundaries, transactions and contracts. This draws in work by Coase (1937), Williamson (1975,

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[14] Keller R, T., 1986, pp 723.

[15] McAllister D., 1995, pp 24.

1991), Stinchcombe and Heimer (1985), Holmstrom and Roberts (1998), Powell (1990) and Baker, Gibbons and Murphy (2002).

A view that resonates amongst the project practitioner community is that the management of megaprojects is essentially about managing risk. Delivering major projects involves managing and responding to an environment with significant degrees of uncertainty. As Miller and Lessard state;

> "Here (LEPs), risks and uncertainty combine with indeterminacy to create ambiguous decision making contexts."[16]

My research therefore incorporates notions of decision making under uncertainty (Kahneman and Tversky 1986, 1992), the challenge of uncertainty within complex system development projects (Browning 1998) and the risk associated with megaprojects (Flyvbjerg 2003).

Finally, 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 nonlinear relationships between components, multiple feedback processes and dynamic environments, makes system dynamics a particularly apt approach (Sterman 1992). However, my research diverges from the traditional system dynamics approach to understanding project pathologies by incorporating multiple firms in the model. A key assumption of much previous work has been that the project organization is within the

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[16] Miller R., Lessard D., 2000, pp 76.

boundaries of one firm, even if it spanned multiple phases (Cooper 1980, Abdell-Hamid 1991, Repenning 2001, Ford and Sterman 1998, 2003, Black and Repenning 2001).

Characteristics of LEPs	Academic Fields					
	System Architecture	Product Development	Organizational Theory	Economics	System Dynamics	Decision Theory
Product Architecture	Maier & Rechtin (2002), Whitney (2004)	Ulrich & Eppinger (2000), Sosa, Eppinger and Rowles (2000)				
Contracts between Firms			Stinchcombe & Heimer (1985), Perrow (1986)	Baker et al (2002), Gibbons (2005)		Lessard & Miller (2001), Flyvbjerg (2003)
Transactions between Firms			Powell (1990), Podolny & Page (1998)	Coase (1937), Dyer (1997), Williamson (2002)		Simon (1991), Zaheer et al (1998), Carson et al (2003)
Multiple Stakeholders	Allen et al (2004), Crawley et al (2004)	Ulrich & Eppinger (2000)	Murman et al (2002), Miller & Lessard (2000)			
Dynamic Behavior					Sterman (2000)	Sterman (1989)
Product Development Processes		Wheelwright and Clark (1992)	McDonough et al (2001), Keller (1986)		Repenning (2000, 2002), Ford and Sterman (1998)	
Uncertainty	Maier & Rechtin (2002)	Browning (1998)	LaPorte et al (1991), Weick & Roberts (1993)			Simon (1959), Tversky & Kahneman (1986)

Figure 1: An Interdisciplinary Landscape

Figure 1 highlights the multiple attributes of LEPS and the range of academic disciplines that have had something to say about these attributes.[17] My work draws upon aspects of each of these traditions in examining how sponsors can build alignment amongst the firms contracted to execute the project.

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[17] Figure 1 is by no means exhaustive, but merely intended to be illustrative. Even a partial list would stretch to many hundreds of papers as a simple search on Google Scholar ™ indicates.

1.6 A Grounded Theory

Six factors that interact to generate the required antecedents of alignment emerge from the analysis of the first-hand interview transcripts, survey results, 3rd party interview transcripts, secondary documents and observations made in the field . The six factors are:

- System architecture
- Organizational design
- Contract design
- Risk
- Metrics
- Incentives

Through a synthesis of these six factors, together with perspectives provided by research into high reliability organizations, economic models of contractual relationships and the abstraction of inductively derived categories to higher level concepts, I generate a theory of alignment amongst firms delivering large engineering projects. The central argument of this thesis is that alignment requires the development of two antecedents amongst the project firms:

(1) A shared understanding of the task at hand (broadly defined), and
(2) A general expectation of other firms' reliable, predictable and fair behavior.

The first of the two required alignment antecedents involves building an environment that shapes decision making towards mutually acceptable outcomes. This requires a rich and detailed shared understanding of the project enterprise and its intent (including constraints, objectives, firm motivations and aims, task requirements etc), complete with decision heuristics to support the selection of particular solutions from amongst alternatives in ambiguous settings, which can be described as a *shared cognitive field* (March and Simon 1958, Simon 1959, Simon 1979).

The second antecedent of alignment is the development of an environment in which firms believe (and act on this belief) that other firms can be relied upon to meet their obligations, behave predictably and act with good-will towards others. Such an environment can be described as exhibiting *inter-firm trust* (McAllister 1995, Zaheer et al 1998, Kramer 1999, Carson et al 2003).

These two antecedents of alignment, act together to build a self-enforcing alignment mechanism as shown below in Figure 2.

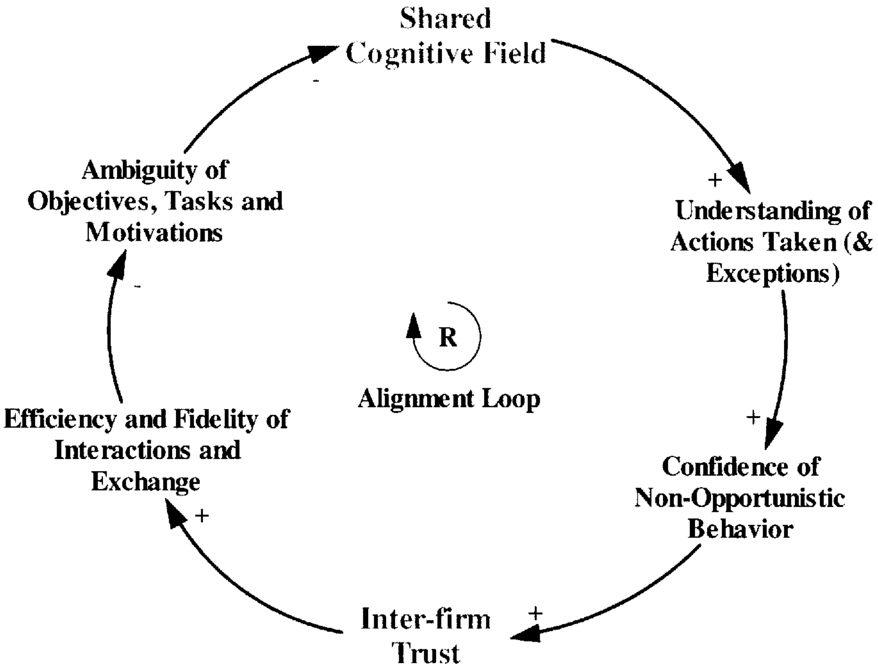

Figure 2: The Self Enforcing Alignment Mechanism

My research indicates that development of the self-enforcing alignment mechanism requires considered and purposive action by the project sponsor(s), and active support from the project contractors. The shared cognitive field and trust based inter-firm interactions are shaped by the use of both formal (contractually or hierarchically specified), and informal (relational or emergent) mechanisms for control and coordination amongst firms. These mechanisms – which I refer to as “alignment mechanisms” - frame the inter-firm interactions which give rise to the antecedents of alignment.

The theory proposed above is a middle range theory (Merton 1968) which is grounded in the empirical observations of a distinct organizational system. My research delivers a set of frameworks that enables project practitioners to focus on distinct domains of influence (formal and informal) with a view to purposively employing specific design variables (the six factors) to deliver the antecedents of alignment (a shared cognitive field and trust based inter-firm interactions). The following chapters will discuss these tools, and the causal mechanisms that they are based on.

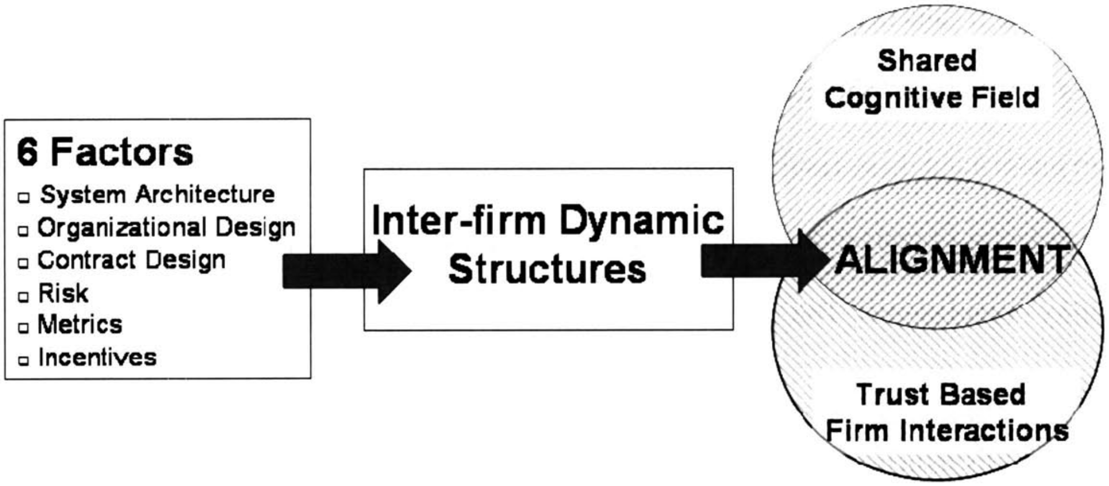

Figure 3: Delivering Project Alignment at the Intersection of Trust and Shared Understanding

1.7 Thesis Outline

My thesis is arranged as follows. In Chapter 2 I present a brief description of projects in general followed by an introduction to large engineering projects and the challenges they face. This description of the attributes of large projects, and their track record of performance, provides motivation for the research. I also offer some speculation as to what underlies their characteristic poor performance. I conclude that chapter with a short discussion of why large engineering projects are examples of engineering systems relevant to the field of Engineering Systems. Chapter 3 contains an illustrative case study from one of the projects I examined. This provides some contextual background for the ensuing chapters as well as further motivation.

Chapter 4 describes the research approach I employed -- grounded theory building -- and the analytic techniques used to understand the phenomenon of alignment. Chapter 5 describes the results that emerged from this process. Part of this description includes an analysis of the results obtained from the formal system dynamics model. In Chapter 6 I seek to understand these results through the perspectives offered by two established frameworks for organizational analysis. The first of these is the research into high reliability organizations. The second framework is offered by contract economics.

In Chapter 7 I synthesize these perspectives, and the insights gained from the formal model, and offer my theory of alignment. Chapter 8 explores the implications of this theory from a practitioner's perspective and offers some guidance as to how alignment can be built in a practical context. Finally I conclude in chapter 9 with a summation of my key findings and offer some thoughts on the possible future direction of work related to this thesis.

2.0 Large Engineering Projects

Projects are distinct organizational forms assembled to achieve specific aims (Cleland 1990). Large engineering projects have some unique attributes that set them apart from most projects. In the next few sections I will briefly describe the nature of projects in general, and the attributes of LEPs in particular. Finally I will suggest that LEPs exhibit many of the properties that are used to demark engineering systems as a unique class of endeavor.

2.1 The Nature of Projects

Projects are sets of activities or tasks, requiring resources, which are organized with the intent of achieving specified goals (Kerzner 1992, Cleland 1990, Ulrich and Eppinger 2000, Blanchard and Fabrycky 2000, Pich, Loch and De Meyer 2002,). They are typically defined by a distinct life cycle, a specified completion date and are usually pulled together to create something that did not exist previously (Cleland 1990). Given the purpose of projects is to create something new, they exhibit many of the challenges associated with organizational learning and knowledge building (Allen 1986, Nonoka 1994, Hansen 2002, Pich, Loch and De Meyer 2002). In this regard they share many similarities with product development processes, but with an important distinguishing feature; projects tend to be temporary enterprises whereas product development is imbued with notions of continuity within an organization even as specific products move through the process (Wheelwright and Clark 1992, Ulrich and Eppinger 2000).

Project management consists of the process of planning, executing and monitoring the activities within a project (Pich, Loch and De Meyer, 2002). Project management is tasked with "the execution of the functions of planning, organization, motivation, direction and control. It includes the management of a project team and coordination with a variety of outside persons, agencies, institutions, and enterprises that have, or feel that have, a vested interest in the project" (Cleland 1990). Project managers wrestle with delivering projects bounded by what is often described as the "iron triangle" or "the triple constraints" of time, cost and scope, or alternatively time, cost and quality (Kerzner 1992, Cleland 1990, de Weck 2003, Jugdev and Muller, 2005).

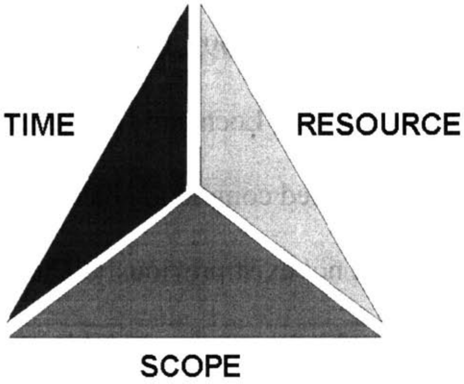

Figure 4: The Iron Triangle

Perhaps because of this mix of iron constraints with organizational learning, and the requisite development of novel solutions, projects have displayed a patchy record of success (Pich, Loch and De Meyer 2002, Flyvbjerg 2003, Williams 2005, Miller and Lessard 2000). Williams (2005) cites numerous studies, including one of 246 U.S. Army programs[18] where cost overruns were up to 400%. He concludes that "common experience is that many projects fail".

2.2 Large Engineering Projects

Modern project management is considered by some (Kerzner 1992, Williams 2005) to have its foundations in the U.S. weapons programs of the 1950s (the Polaris missile) and the U.S. space program. These projects transformed their environments, and arguably the way modern firms operate (Kerzner 1992). Large engineering projects continue to do the same thing. Miller and Lessard (2000) define large engineering projects (LEPs) as "unique, dedicated, and usually one-off products with intensive interactions between sponsors and contractors." These projects tend to develop large scale, singular, indivisible systems with long duration life-cycles whose societal impacts may last generations (think of major transport and energy infrastructure). And, the number, complexity, scale and cost of these transformative projects has been growing rapidly in the last few decades (Miller and Lessard 2000, Flyvbjerg 2003)

2.2.1 Attributes of Large Engineering Projects

LEPs are distinguished from most other forms of projects by the following attributes:

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[18] Arbogast G, W., Womer N, L., 1988.

1. The involvement of multiple firms. Most projects take place within the confines of a single firm. LEPs by contrast are of a scale that makes this impractical. LEPs manage risk by diversifying financing and ownership across multiple stakeholders (Miller and Lessard 2000, Flyvbjerg 2003). Sponsors of LEPs partition the system to be developed into discrete elements to take advantage of market specialization in the provision of technology and services (engineering, construction, etc).
2. Long duration. LEPs have product development cycles --from inception, planning, engineering fabrication/construction to implementation -- that frequently span a decade or more. The IMEC[19] sample averaged 10.7 years from inception to completion. The five projects that I investigated began initial planning in the mid to late nineties and are averaging over 7 years from initial discovery of the field to the start of production.
3. Substantial Risk. While all projects contain uncertainty and ambiguity, and thus risk, LEPs are almost defined by the risks they face. Projects of this scale (upwards of $1Billion) face not only demanding technical risks, but also financial, market, institutional, social acceptability, and regulatory risks (Miller and Lessard 2000, Flyvbjerg 2003). These are interdependent and unfold dynamically (Miller and Lessard 2000).
4. Dynamic and Emergent Behavior. The field of system dynamics has been particularly engaged with trying to understand project behaviors, principally because the nature of large scale projects, defined as they are by highly nonlinear

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[19] Miller and Lessard (2000) reported on the results of the IMEC (International Research Program on the Management of Large Engineering and Construction Projects) study into LEPs. The 60 projects had an average cost of $1Billion.

relationships between components, multiple feedback processes and dynamic environments, makes system dynamics a particularly apt approach (Sterman 1992, Repenning 2002, Sterman 2000). LEPs are complex systems that feature structural complexity (number of elements and their connections) and uncertainty (in goals and means to achieve them) and as a result they feature emergent behavior (Williams 2005, ESD Monograph 2004)

2.2.2 The Performance of Large Engineering Projects

Perhaps as a result of interactions among the attributes listed above LEPs of almost all categories and types provide multiple instances of poor performance. Miller and Lessard (2000) reported that 40% of the sixty projects they studied[20] performed "very badly", while 28% missed their schedule targets. Flyvbjerg (2003) reported a US Department of Treasury study of ten US Rail transit projects with a total value of $15.5 billion (1998 prices). The total cost overrun of these projects was 61%, ranging from -10 to +106 per cent for individual projects.

The "model" for my research of LEPs was deepwater offshore hydrocarbon extraction projects. As examples of LEPs offshore oil and gas developments display typical project performance. For example, a recent study reviewed the performance of fourteen billion dollar plus mega-projects (Merrow 2003) - eleven of them offshore developments - executed by the oil and gas industry in the last 20 years. The average cost growth was 46% over the authorization estimate, with half the sample exceeding 40% cost growth.

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[20] Miller and Lessard (2000) reported on the IMEC study. See previous footnote.

The total value of this cost creep was $11.8 billion. Schedules also slipped by an average of 28%, with the seven worst projects slipping an astounding 39%. By way of comparison this study also reported that, over the same period, the average shallow water project (with a capital cost approximately 1/10th of the mega-projects) experienced an average of 2% cost growth (Merrow 2003). The performance of the offshore mega-projects also displayed a bi-modal characteristic. The average cost growth of 46% was skewed by the half of the projects that had over 40% cost growth (see Figure 5).

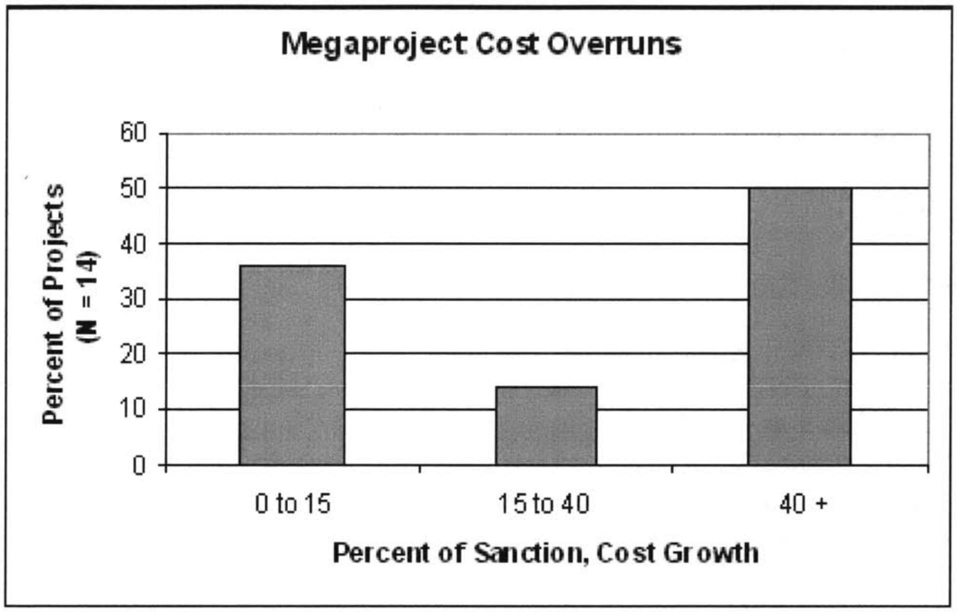

Figure 5. Bi-modal Distribution of Cost Overruns

Data from the sponsor firm I was researching showed a similar pattern for a sample of eleven recent projects. Sixty seven contracts from eleven projects had a combined value of $6.1billion with an average project value of $550 million. Again we see a bi-modal distribution of cost growth (see Figure 6). A small but sizeable set of projects perform relatively well (under budget to 15% cost growth) with a large percentage of projects performing very poorly (20% cost growth or greater).

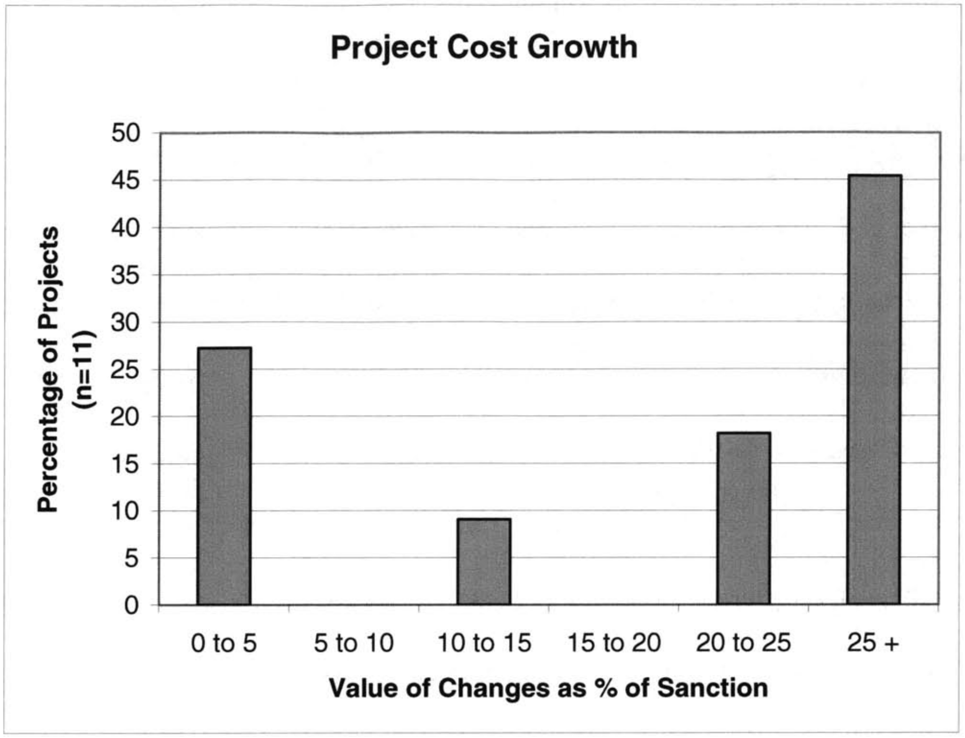

Figure 6. Distribution of Project Cost Overruns

The takeaways from this description of the attributes and performance of LEPS are:

1. That these are highly complex systems, and
2. Despite their crucial impact on our society we struggle to deliver them successfully.
3. Traditional product development/project management techniques developed for small scale projects (such as the design of new consumer products, for example a cell phone) do not appear to be effective in regard to these systems (Williams 2005).

4. When these large complex projects display poor project performance (i.e not meeting cost and schedule) they perform *very* poorly.

It is tempting to speculate with respect to the driver(s) of this last observation about LEPs. Why do they perform so badly when they fail? This bi-modal behavior suggests that LEPs exhibit some form of "tipping point" behavior (Repenning 2000, 2002, Repenning et al 2001) or that they feature a dominant reinforcing causal structure that can operate in either a beneficial or detrimental fashion (Weick 1993, Sterman 2000). When working beneficially the mechanism sustains the desired project performance, but when it operates otherwise, the results are massive cost overruns and schedule delays. Furthermore it appears that smaller projects (at least in the offshore sector) do not appear to display this same bi-modal behavior suggesting that the mechanism(s) driving this phenomenon is possibly unique to, or at least more keenly felt by, large projects.

2.3 Large Projects have "System" properties

The final point I want to make in this introductory chapter is that LEPs exhibit many of the attributes and properties that we use to describe complex engineered systems. This should come as no surprise as it is through LEPs that many of these engineered systems (oil and gas facilities, air transport infrastructure, aircraft, weapons systems, to name a few) are actually developed. Moses in the 2004 ESD Monograph, *Foundational Issues in Engineering Systems: A Framing Paper,* establishes the foundational issues for a new field of study, that of Engineering Systems, which is concerned with the study of large scale complex engineered systems. The foundational issues associated with such systems are architecture, uncertainty, flexibility, safety and sustainability (Moses 2004). These issues are likewise central to large engineering projects, and the enterprises that enact them.

To begin with, the product system being developed by a project can be described in terms of its architecture; is it integral or modular (Sosa, Eppinger and Rowles 2000, 2003)? This has a bearing on how the firms interact. The extent to which the system(s) under development can be described as integral has important implications on the development process. As Novak and Eppinger (2001) point out "the more interconnected are the parts of a system, the more difficult it is to coordinate development"[21].

The project can display robust or brittle behavior in the face of system perturbations (labeled as "turbulence" by Miller and Floricel 2000); the project may, or may not be able to "maintain its operational capabilities under different environments."[22] And as we have seen from the description above, the project is likely to face a number of unpredictable threats and events, thus the project organization needs to be designed in such a manner that enhances the ability of the LEP to display robust behavior. As stated by Moses in the ESD Monograph, *Foundational Issues in Engineering Systems: A Framing Paper*, a key issue in the field (Engineering Systems) is managing change. This issue is central to the challenge posed by large engineering projects.

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[21] Novak S., Eppinger S, D., 2001, pp 190.
[22] de Neufville et al., 2004, pp 10.

Large projects, particularly energy projects, are primarily concerned with safety; safety of the workforce during the projects design, construction and installation, and safety of the personnel that will ultimately operate the facility. A well developed safety culture is central to the most large engineering projects. Finally, and in addition to the foundational issues, large engineering projects display emergent properties. While projects are (or should be) planned as carefully as possible (Cleland 1999), they frequently have to contend with unexpected events; some generated exogenously, others endogenously (Kerzner 1992). The response to these events may cause changes to the product system being developed, or to the project enterprise. In either case a new project emerges with unexpected properties.

3.0 Illustrative Case Studies

Large oil and gas projects evolve over several years and the "*House*" 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. The other major projects I studied were "*Glory*" in the Gulf of Mexico; a North Sea project, "*Indian*"; and a West African project, "*Party*"[23]. Each represented significant investment, and risk, for the project sponsor and the engineering contractors engaged on the project.

3.1 Multiple Project Strategy: House, Indian, Glory and Party

Toward the early 1990's the sponsoring firm 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 offshore energy industry's capabilities. In several specific technology and service areas (such as offshore installation, pipe manufacturing, and shipyards) a shortage of the assets required to execute the projects was anticipated and a contracting strategy to mitigate these pinch points was developed. In an effort to secure access to the human and physical

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[23] These are not the actual names of the projects. The project sponsor providing access for the research preferred that the projects not be identified. I have used pseudonyms for the project names, and "pseudo-locations" for the regional locations of the projects. Some technical details have also been adjusted to maintain confidentiality, but have been changed in such a way as to maintain explanatory significance. In all other respects the events, quotes and timelines are accurate.

resources needed the sponsor developed a "multiple project contract strategy" (MPCS). This approach awarded contracts to the engineering service providers not for each individual project, but for the portfolio of projects.

Each project within the MPCS was a major investment requiring sustained effort over multiple years, and this approach represented a departure from the industry norm. The strategy appeared to offer several advantages over traditional contracting. First, the MPCS seemed to guarantee the 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 (the contractors) would reduce the price of their services. It was expected that despite reduced rates (and consequent savings for the sponsor), contractors would be able to maintain earnings through the repetition of key design elements amongst the projects resulting in scale efficiencies. In addition, project execution efficiency would be enhanced through the creation of 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. The MPCS was envisioned as a way of aligning the sponsor and the contractors but what should have been a classic "win-win" in fact evolved into the all too common "lose-lose" associated with LEPs. Projects ran over budget and behind schedule, relationships became adversarial and some contractors claimed to be losing money. To simplify the case study, I will focus on just one of the projects, but this project is representative of the projects associated with the MPCS.

3.2 House: A Large Engineering Project

The *House* project was, at the time, one of the largest offshore oil and gas developments being undertaken anywhere in the world. The field is located some 130 miles off the Louisiana coastline in over a kilometer (3000ft) of water. The oil reserves lie at a depth over 15,000ft below the seafloor. When the platform reaches full production it will produce of 100,000 bpd of oil and over 150MMcf/d of natural gas. The platform power generation plant, housed on the hull topsides, provides some 60MW. The hydrocarbons are produced at pressures exceeding 10,000psi and at temperatures over 200 degF. Subsea systems have to withstand these pressures and temperatures while also resisting external conditions of near freezing water temperatures and over 100bar of pressure. At the time of sanction (approval for development by the project owners), the project was expected to cost nearly $1 billion.

The key system elements are shown in the following functional system decomposition:

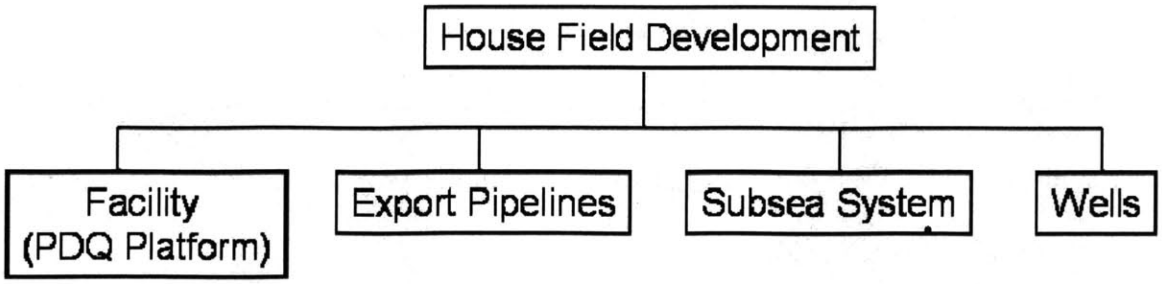


Figure 7: System Decomposition by Major Components

(PDQ: Production Drilling and Quarters)

Major system elements are decomposed below to level 2 functional descriptions:

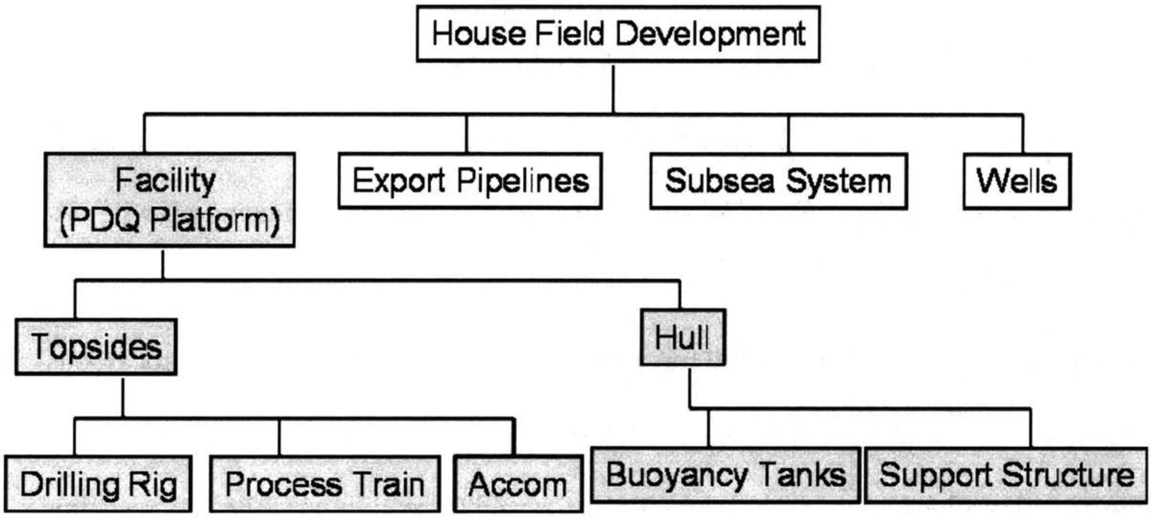


Figure 8: Functional Decomposition of the *House* Facility

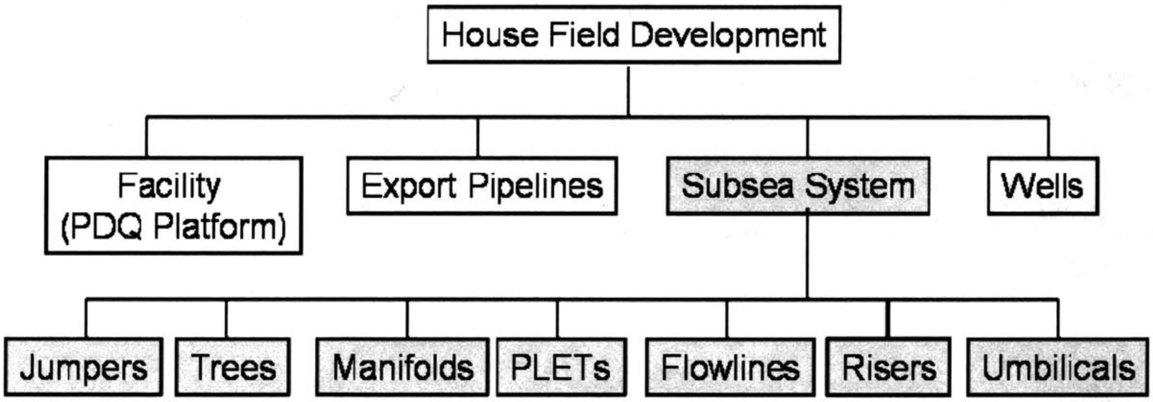


Figure 9: Functional Decomposition of the *House* Subsea System

Design and fabrication of each of the above systems was a multi-million multi-year engineering endeavor involving numerous firms. Figure 10 illustrates this:

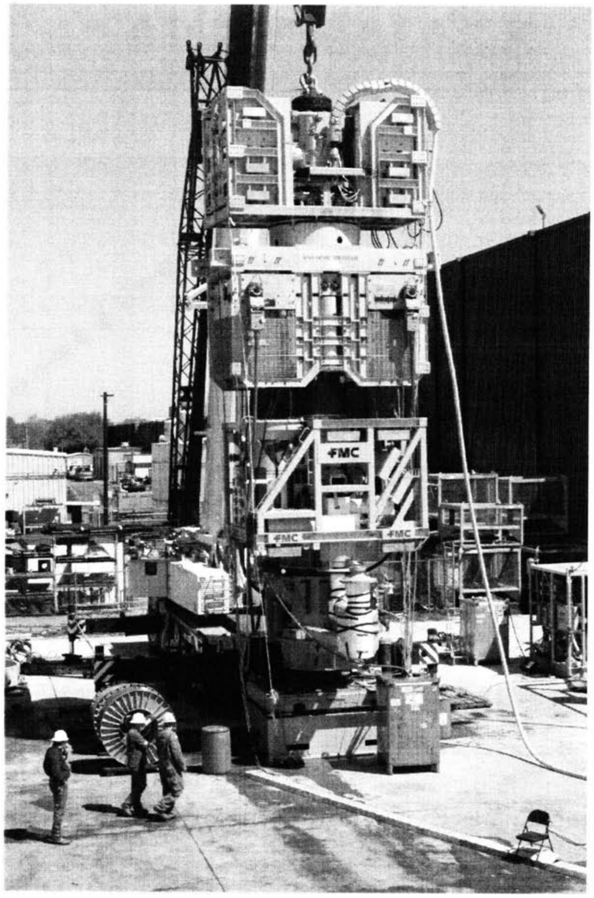
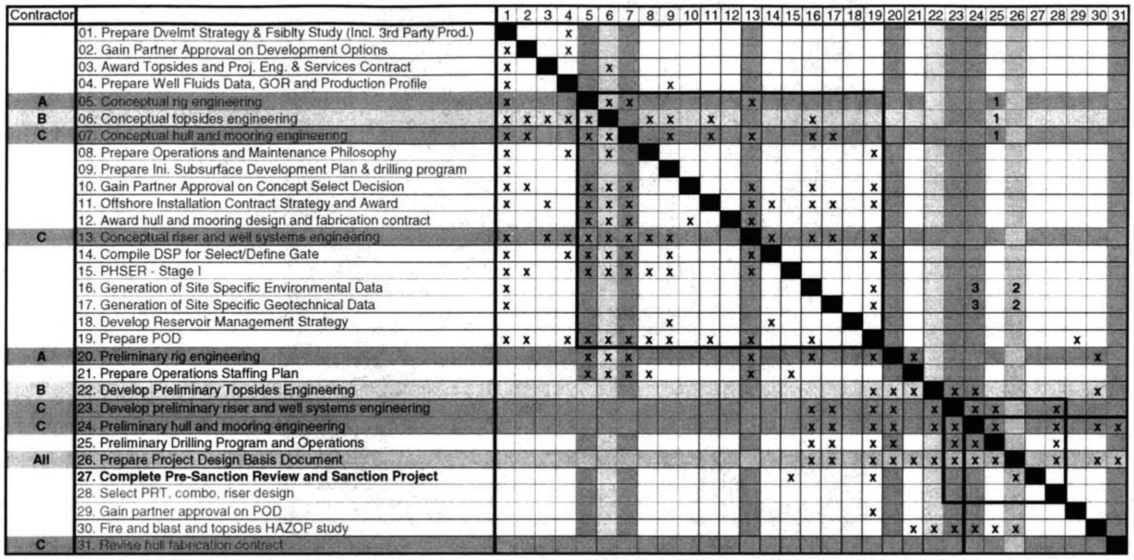


Figure 10: Assembling a Subsea Well

As discussed in Chapter 3, LEPs feature multiple firms being assembled to execute the project. *House* was no exception. The following partial DSM is taken from the full DSM developed by the team of sponsor senior managers responsible for the *House* project. It is a very high level description of the set of project activities; for example item 24 is "Preliminary Hull and Mooring Engineering", itself a 12 month, multi-million dollar effort! The partial DSM shown in figure 11 shows the first 31 activities and shades separate scopes of work for four tier one suppliers. The full DSM ran to 80 items (with each item representing multiple year, multiple million dollar efforts) and covered the scopes of 10 suppliers.



Contractor		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	01. Prepare Dvelmt Strategy & Fsiblty Study (Incl. 3rd Party Prod.)	■			x																											
	02. Gain Partner Approval on Development Options	x	■		x																											
	03. Award Topsides and Proj. Eng. & Services Contract	x		■			x																									
	04. Prepare Well Fluids Data, GOR and Production Profile	x			■					x																						
A	05. Conceptual rig engineering	x				■	x	x						x												1						
B	06. Conceptual topsides engineering	x	x	x	x	x	■		x	x		x					x									1						
C	07. Conceptual hull and mooring engineering	x	x			x	x	■		x		x		x			x	x								1						
	08. Prepare Operations and Maintenance Philosophy	x			x		x		■											x												
	09. Prepare Ini. Subsurface Development Plan & drilling program	x								■																						
	10. Gain Partner Approval on Concept Select Decision	x	x			x	x	x			■			x			x			x												
	11. Offshore Installation Contract Strategy and Award	x		x		x	x	x				■		x	x		x	x		x												
	12. Award hull and mooring design and fabrication contract					x	x	x			x		■	x																		
C	13. Conceptual riser and well systems engineering	x		x	x	x	x	x	x	x				■	x		x	x		x												
	14. Compile DSP for Select/Define Gate	x			x	x	x	x		x				x	■					x												
	15. PHSER - Stage I	x	x			x	x	x	x	x				x		■																
	16. Generation of Site Specific Environmental Data	x															■			x					3		2					
	17. Generation of Site Specific Geotechnical Data	x																■		x					3		2					
	18. Develop Reservoir Management Strategy									x					x				■													
	19. Prepare POD	x	x		x	x	x	x	x	x		x		x			x			■										x		
A	20. Preliminary rig engineering					x	x	x						x			x			x	■	x									x	
	21. Prepare Operations Staffing Plan					x	x	x	x					x		x						■										
B	22. Develop Preliminary Topsides Engineering																			x	x	x	■	x	x						x	
C	23. Develop preliminary riser and well systems engineering																x	x		x	x		x	■	x	x			x			
C	24. Preliminary hull and mooring engineering																x	x		x	x		x	x	■	x			x		x	x
	25. Preliminary Drilling Program and Operations																x	x		x	x			x	x	■			x			
All	26. Prepare Project Design Basis Document																x	x		x	x	x	x	x	x	x	■		x		x	x
	27. Complete Pre-Sanction Review and Sanction Project															x				x							x	■				
	28. Select PRT, combo, riser design																												■			
	29. Gain partner approval on POD																			x										■		
	30. Fire and blast and topsides HAZOP study																					x	x	x	x	x	x				■	
C	31. Revise hull fabrication contract																															■

Figure 11: Partial DSM of House with Contractor Responsibilities Shaded

Figure 11 provides some clue as to just how complex the interrelationships and dependencies amongst sponsor and contractors are on projects of this scale. A simpler diagram is shown in Figure 12. The system decomposition from Figure 7 is shown with corresponding scopes of work added in the dashed boxes below each system element (the scopes of work associated with the hull – i.e. design, fabrication, transportation – are not shown due to space limitations). Each scope of work (a dashed box per scope) is then shaded to indicate its allocation to a specific contractor. 11 distinct firms are responsible for the 14 scopes of work included in the diagram.

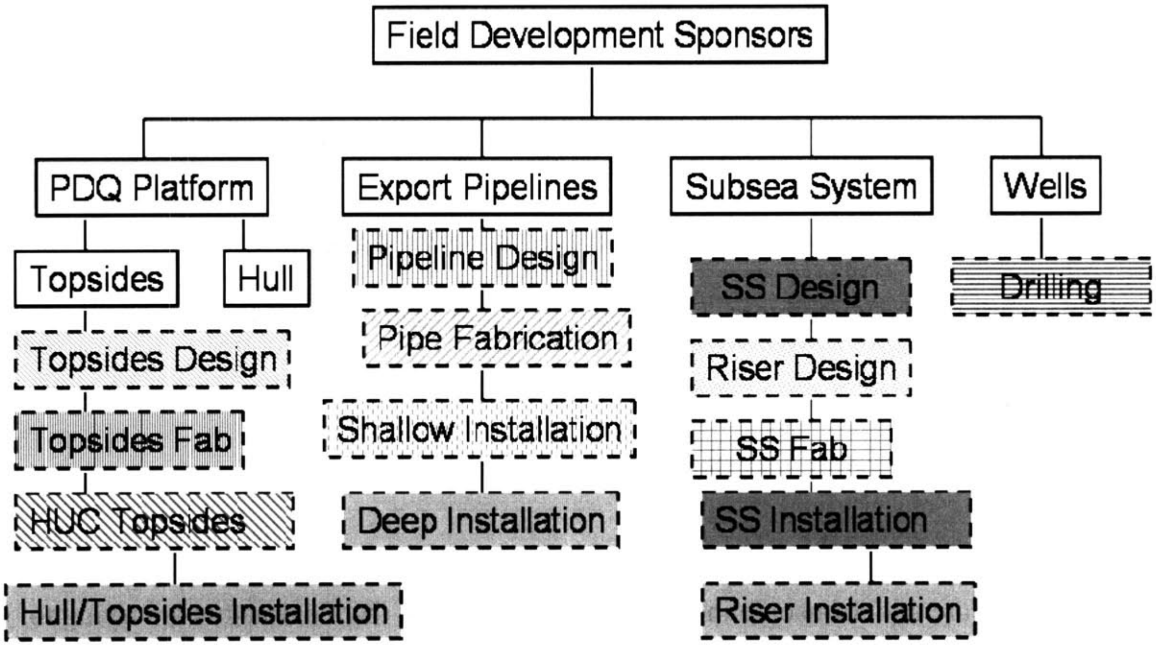


Figure 12: Contractor Scope Decomposition

3.3 How the Project Unfolded

The chart below lays out some critical events related to the *House* development.

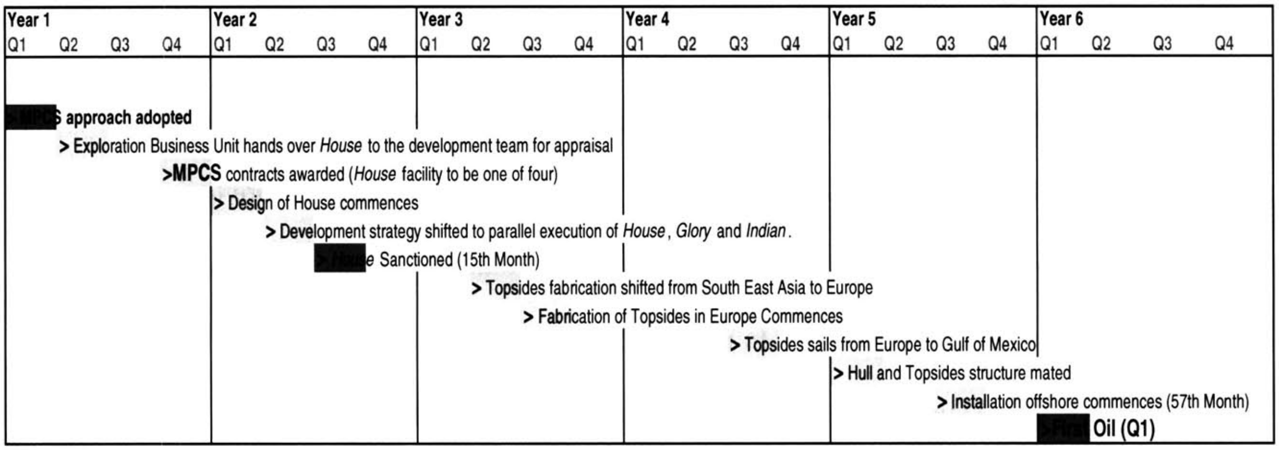


Figure 13: Timeline of *House* Topsides Contract and Project Execution

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 the sponsor 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 the sponsor's perspective the use of scale to create bargaining leverage was justified by the view 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 MPCS contracts were awarded to key contractors. These were established despite the fact that very little preliminary design had taken place, indeed, even before some projects (such as *House*) 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 the sponsor 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 *House* and *Indian*. All the projects faced numerous changes to their designs late in the development cycle and carried the costs of the resulting variation orders.

3.3.1 A change of direction

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 MPCS of projects had changed. Executive management at the sponsor determined that the schedule for the projects should be compressed from a sequenced approach to a parallel one[24]. 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".

Design work on *House* commenced early in Year 2, shortly after the MPCS contracts were awarded and before the change in contract schedule was announced. It wasn't until the third quarter of Year 2 that *House* was officially sanctioned. At about this time the

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[24] The reasons for this decision are beyond the scope of this research, but managers interviewed suggested the following possible motivations: Firstly, to 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 next decade (the 00's).

project teams for *Party* and *Glory*, 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 *House* and *Indian*. The system architecture of the platforms and subsea systems needed to change.

The contractors were now facing not one coordinated MPCS of similar projects, but essentially four unique projects. Consequently the existing contracting framework and working relationships came under pressure and problems began to materialize. The contractors had "given the sponsor 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 the sponsor, each of which was demanding that their specific needs be met. The events surrounding the construction of the topsides for *House* highlight some of the challenges that appeared.

3.3.2 Changing Contractors

The fabrication of the topsides and deck structure for *House* (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 desired 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 MPCS contracts and as the full complexity of the *House* design became apparent they began to use variation orders extensively as a strategy to enhance their profitability. The sponsor had agreed a reimbursable contract[25] with a "target" price. The target was reached within a matter of months with less than 30% of the work completed. The relationship between the sponsor and the contractor deteriorated markedly, with each side blaming the other for the state of affairs; the sponsor blaming the contractor for overspending the target budget, the contractor blaming the sponsor for not having fully specified the complexity of the project.

In addition, the *Indian* project was also being fabricated by the same contractor and thus the two projects were competing with each other for a limited pool of resources. The topsides experience was not unique, however. A second contractor on the *House* project (hull fabrication) also experienced difficulties in meeting their obligations.

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[25] Reimbursable contracts, broadly speaking, are structured to pay contractors their costs plus a specified profit margin. They can be organized around a bill-of-quantities, bill-of-rates, or combinations of these. However, in essence they are generally "open ended" to cover highly uncertain activities where fixed prices are difficult to determine.

3.3.3 Problems at Home

The main structure for *House* 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 MPCS strategy. This major element of the project also suffered from significant cost overruns. The contract had been awarded to a firm whose physical assets (a fabrication yard) was deemed to be strategic to the success of the projects. However, problems occurred because, as was stated during an interview with one of the sponsor's senior managers:

> "they told us that they had the labor to do the job, but they didn't".

The contractor in question suggested that a contributing factor for the delays was that:

> "No one (from the sponsor) was in a position to make decisions... ...it takes weeks to get a decision made, and when they do, other projects (from the same sponsor) complain."

In addition early delays in finalizing some aspects of the design had meant that the sponsor risked an idle yard that they were obliged to pay for. Rather than allowing this to happen they pushed for the contractor to begin fabrication of some standard elements of the system out of normal sequence. This enabled work to begin, but as designs began to be finalized much of the already fabricated elements had to be adjusted to suit.

In the end the sponsor had to revise their management approach (of independent projects) and appoint a single individual who had authority over all the sponsor's projects sharing the same facility. 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 *House* finally commenced. In the opening months of Year 6 *House* delivered first oil and the project was completed.

3.4 Outcomes

The *House* 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 *Hous*e. In the end the project was delivered 6 months late and nearly 50% over budget and with serious contractual disputes arising with a number of contractors.

The outcome of the *House* project, and the events that unfolded during its duration, prompt a number of questions. Firstly, it appears that once a project gets "off-track" it is almost impossible to turn it around. Why is this so? Secondly, it is safe to assume that neither party to a contractual dispute wants that to be the outcome from a particular project (especially when the firms are working together on other projects). So, how does such gross misalignment occur? If we can understand how things can become so poorly aligned, perhaps that will point us towards how to deliver genuine alignment.

4.0 Methods and Analysis

I used grounded theory building methodology (Strauss 1987, Strauss and Corbin 1990, Creswell 1998, Goulding 2002), supplemented by causal loop diagramming and formal simulation model building (Sterman 2000), in order to generate an understanding of the micro-foundations of alignment. The research process was one of iterating between observation, inductively derived categories complete with causal inferences, causal loop diagrams, relevant literature and formal mathematical models to generate a grounded qualitative theory. This process followed the recommendation of Weick (1989), reflecting on Bourgeois (1979), to "weave back and forth between intuition and data based theorizing and between induction and deduction"[26].

4.1 Why Grounded Theory Building?

There are two reasons why I selected grounded theory building as the most suitable method for my research. Firstly, where there is a paucity of existing theory it is an appropriate choice (Strauss 1987, Strauss and Corbin 1990). Secondly, the method's saliency to my phenomenon of interest is compelling.

Despite the ubiquity of projects and the existence of professional bodies dedicated to assisting project managers (such as the Project Management Institute) our understanding

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[26] Weick K, E., 1989, pp 518.

of projects is still nascent (Shenhar 1998). Literature in this realm has tended to be based on descriptive case studies and "war stories" (Kloppenborg and Opfer 2002). The focus has been on normative advice on project planning and execution (e.g. Kerzner 1992, Cleland 1999, Flyvbjerg 2003) with little attention paid to developing theoretical underpinnings. The result is a dearth of testable theories for how, and why, the normative advice offered to practitioners actually delivers project performance (Shenhar 1998, Jugdev 2004). There have been a few notable exceptions, the excellent study of Norwegian offshore oil and gas projects by Stinchcombe and Hiemer (1985) being an example. In a context of limit theoretical development grounded theory building offers a way forward (Strauss1987, Creswell 1998, Goulding 2002).

I have also attempted to match my research method to the phenomenon to be investigated. My focus is on the micro-foundations of alignment, and by "micro-foundations" I mean actions taken by individuals within firms that shape how firms, and other individuals, act and react to each other. These are small actions with large consequences (Weick 1993). I am interested in how individuals make choices with respect to building alignment. How they perceive it, why they make the choices they make and how they react to the environment they find themselves in; an environment largely constructed by the actions of other individuals (Weick 1993, Weick, Sutcliffe and Obstfeld 2005). It is important that the context of the phenomenon I am investigating be retained by the research method. Grounded theory building is almost unique in being able to offer techniques that allow for abstract conceptualizations of causality to emerge while retaining rich contextual information.

4.2 Approach

My research approach integrated the following key elements:

- Data collection from interviews, observations and documents.
- Literature, as a resource for understanding and insight and for quasi-validation.
- Inductively and deductively derived causal relationships.
- Formal simulation model building.

Drawing on experiential data (Strauss 1987), I approached the problem with an intuitive notion of how to unpack the problem and gain early traction. Based on this, and following the tenets of theoretical sampling (Strauss 1987), I began my data collection with a series of interviews of senior project managers (see Section 4.5 Data Collection below). Intuition was transformed into theory through engaging the rich data set and generating causal relationships grounded in observation. These were tested and extended by employing the constant comparison method (Strauss 1987, Strauss and Corbin 1990). Observations from interviews were compared among informants for consistency and between informants and documentary evidence (Dyer 1997). I extended this method to include comparison between emerging causal hypotheses and established literature and between the results from formal models and informant observation (Sterman 2000).

4.2.1 Research Activities

The research activities are enumerated below, and discussed in greater detail in the following sections. However it is important to recognize that while the steps are laid out as though they were distinct and sequential activities it was an iterative integrative process that occurred. The process is represented in a diagrammatic fashion in Figure 14.

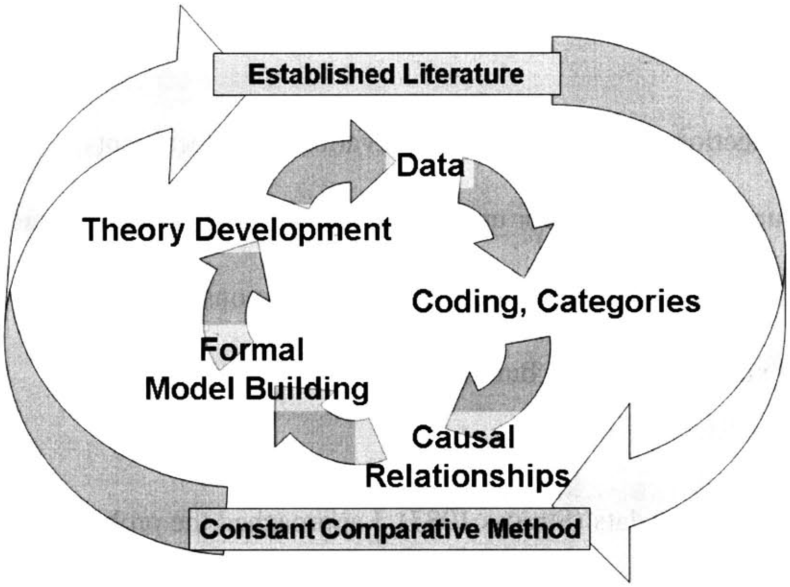

Figure 14: The Research Method

The research progressed along the following steps:

1. Began by approaching the problem with experiential data.
2. Using intuition derived from experience, and the tenets of theoretical sampling, propose and conduct an initial set of interviews.
3. Gather secondary data (archival records, transcripts of third-party interviews etc).
4. Using established qualitative methods code and sort observations into a set of emerging categories.
5. Propose causal relationships amongst these categories and capture them through causal loop diagramming.

6. Build a formal dynamic simulation model incorporating the inductively derived causal relationships and drawing upon existing documented models.
7. Simulate model and compare results to informant observation, archival sources and literature.
8. Present the results from the model, and associated causal relationships, to practitioners (including original informants) through presentations and workshops to elicit feedback and validation.
9. Based on the responses from the feedback, return to primary sources for further data collection (interviews).
10. Continue to develop the formal model and test against literature, observation and primary data.
11. Develop a theory of alignment micro-foundations incorporating a set of tools suitable for use by practitioners in the field.

4.3 Formal Model Building

4.3.1 The Utility of Models

Formal model building was an essential component of my research approach. Formal modeling provides needed analytic and explanatory power to supplement the rich qualitative understanding of events. System dynamic models are particularly useful for understanding complex managerial systems (Roberts 1978, Sterman 2000). They achieve this utility in a number of ways. First, system dynamics is a research technique founded on the precept of examining dynamic patterns of behavior over time, where such patterns are the result of feedback mechanisms generated by the system structure (Roberts 1978). System dynamics is thus ideally suited to investigating the effect of organizational structure on project based endeavors (Sterman 2000, Ford and Sterman 1998). Second, system dynamics modeling requires a rigorous approach to understanding the problem through the decomposition of the structure into elements such as stocks (accumulations of resources or objects) and flows (the movement of people, money, materials, orders etc). Assembling these elements into the simulation model requires rigor in understanding how the system "fits" together; how work is completed, how managerial policy influences resource allocation, how profit and costs are generated and how these elements of the system interact over time.

Third, a formal rigorous model can capture system complexity, feedback interactions and counter-intuitive behavior that qualitative models cannot. Qualitative models, "mental", diagrammatic or descriptive, can only deal with a limited amount of complexity, and struggle with time dependent delays and feedbacks (Roberts 1978, Sterman 2000). A formal model overcomes the limitations of qualitative models. Fourth, formal models allow simulation and hypothesis testing. Alternative policies can be proposed and the influence on the system tested by comparing the model outputs. Sensitivity analysis can be conducted on assumptions built into the model. System elements can be isolated and boundaries tested. All of these testing and validation processes are difficult, if not impossible in qualitative models.

Finally, a formal model provides an excellent communication tool. Model output, in the form of graphs and charts, delivers a rich medium for communicating complex ideas to others, be they fellow researchers, or subjects of the research. Patterns of behavior that represent real world experience can be shown and compared with data or practitioners experience. In this way, the use of formal models greatly enhances the development of grounded qualitative theory.

4.3.2 Model Building Methodology

The formal model I built as part of this research included elements derived inductively from data, and deductively from existing models and literature. The modeling process followed the five step best practice recommended by Sterman (2000). Causal loops were developed during and after interviews, often with the involvement of the interview subjects. Presentation of the causal hypotheses, and reference modes, to industry practitioners was an essential part of the model building process and their comments were incorporated into the casual loops and ultimately the formal model. In addition to the inductively derived causal loops, relevant literature was referenced to provide model elements. My formal model was based upon various well understood and documented project models (Roberts 1978, Lyneis, Cooper and Els 2001, Ford and Sterman 1998, Repenning 2001). The foundational project mechanisms of rework, schedule pressure and task errors were incorporated into my model. Additional causal loops were derived deductively from literature outside of system dynamics, for example literature on team dynamics and trust based organizations provided data for the generation of causal mechanisms relevant to my research and model

The next step was model simulation and quasi-validation. The first model was built as a small "insight model" and as such was not formally validated against project specific quantitative data. However, results from the model were compared with literature to derive "1st order" validation. Furthermore, results were presented in a number of workshops to various industry groups, including individuals who had been interviewed, and their feedback and comments incorporated. Finally, a sensitivity analysis of the model was carried out to test which assumptions and parameters built into the model had significance in determining the model behavior. The whole process was highly iterative following a cycle of causal loop diagramming, presentation of hypothesis to practitioners, model building and simulation, presentation of results, and a return to causal loop analysis and model modification and simulation.

4.4 Use of Literature

Lessons from the literature were integrated into the research in a number of ways. First, the literature provided a set of frameworks through which to understand, and approach, the unfolding causal relationships. An example of this is the insight gained from the economics literature with respect to the distinction between formal and informal (relational) contracts (e.g. Macauley 1963, Baker, Gibbons and Murphy 1994, 2002, Gibbons 2005, 2006). Second, I used others' investigations to deepen my understanding of the phenomena I was exploring. For example, the High Reliability Organization literature was particularly useful in explaining the foundations of trust and reciprocity in dynamic team environments (e.g. Weick 1993, Weick and Roberts1993, Carroll et al 2002). Third, the development of the formal mathematical model was enhanced by a deductive process of incorporating well developed and documented mechanisms from analogous models (e.g. Ford and Sterman 1998, Repenning 2000, 2002).

Finally the literature was used not only as a source of ideas with respect to the problem, as highlighted above, but also as a quasi-validation and testing process. When my research suggested the existence of a particular mechanism for generating alignment, I would engage the literature to see what, if anything, others had found in similar environments, or if that particular mechanism had been identified and described in existing literature.

4.5 Data Collection

4.5.1 The Projects

The sponsor company was in the midst of executing a number of large projects concurrently, utilizing the same contractors, predominantly in one geographic region. The company supported my research by providing access to senior project managers responsible for these projects. My investigation was contemporaneous with the progress of four major developments: *House*, *Glory*, *Indian* and *Party*. In addition to the four contemporaneous projects, one historical project was used as a source of data, including interview subjects. *Norse* had been completed in the late 1990s by the company and was similar in scale, complexity and capital spend to the current projects, but featured a different formal contract structure.

4.5.2 The Data:

The data collected conformed to three of the four categories of qualitative information established by Creswell (1998): Interviews, observation and documents. Where possible data was collected that provided the following:

- Vertical data. Within a specific project or organization, primary and secondary sources that provided data from different hierarchical perspectives are selected.
- Horizontal data. Primary and secondary sources from across organizations/projects at the same hierarchical perspective or across multiple contractors engaged on a specific project are sought.
- Longitudinal data. Primary and secondary sources are used that provide data at different points in time, relative to a specific project or contract.

Primary data (interview and observation) was collected through semi-structured in-depth interviews with personnel from the sponsor and key contractors, as well as recording observations made while participating in and facilitating workshops related to contracting (Creswell, 1998). In addition I spent three months working day-to-day in the sponsor company's Houston office. In what could be described as "diagnostic action research" (Susman and Evered, 1978), I worked with managers from the sponsor company to develop a process for delivering alignment between themselves and their major contractors. I also assisted a team tasked with developing a process for the establishment of contract strategies for major projects. Furthermore I attended working sessions of another team preparing the final reports based on an in-depth investigation into the recent set of projects administered from the Houston office (more on this effort below). My participation in the various workshops and team projects was abetted by my own years of experience in this industry (as a staff member for contractor firms) and allowed me to add experiential data (Strauss, 1987) to the information collected.

Project documentation and archival artifacts provided a further rich source of data (Strauss 1987, Strauss and Corbin 1990). The secondary sources of information included internal company reports and white papers on contracting issues and recommended best practices, project post-completion "lessons-learned" reports, retrospective assessments of company projects carried out by independent consultants, publicly available sources such as articles in trade publications, media reports and the archives of governmental agencies (e.g. the Minerals Management Service which approves all developments in the Gulf of Mexico).

4.5.3 Interviews

The interviews, which typically lasted an hour to an hour and a half, followed a semi-structured format with a prepared set of questions to provide consistency. However subjects were allowed to follow their thoughts on any particular topic. Where the subjects felt comfortable with it, the interviews were recorded. For non-recorded interviews detailed notes were taken during the interview.

Following the norms of theoretical sampling (Strauss 1987), I selected two broad categories of interview subjects; project sponsors and contractors. Wherever possible the sponsors and contractors were matched on particular projects. That is to say, if the sponsor's managers for a particular project were interviewed, then the managers, for at least one contractor, engaged on that project were also interviewed. In the case of the contemporaneous projects managers from four contracting organizations engaged on these projects provided interviews. In addition non-matched interviews were conducted with both project sponsors and contractors to provide external reference for comparative validation.

Within each category (sponsor, contractor), and where possible, interviews were conducted to provide both vertical and horizontal data. By this I mean interviewing, within one project, managers that reflected the hierarchical structure of that project as well as managers at the same "level" across different projects. The initial set of interviews was facilitated through contacts with the integrated oil company that was supporting my research. I identified managerial positions within a nominal project and my company champion organized for these individuals, from a specific project, to be made available to me. Subsequent interviews were both opportunistic, as interviewees suggested other contacts, and by design as I sampled managers from unrelated, though comparable, projects. Interviews continued until saturation occurred (Strauss 1987, Strauss and Corbin 1990, Goulding 2002).

One project in particular provided both longitudinal (over time) and vertical data. *House* was an active project at the time of the research. It was also one of the projects that were using the same set of contractors for execution under the multiple project contracts strategy (MPCS). Within this project the following managers were interviewed (See Table 1 for the list of all interview subjects):

1. Offshore Supply Chain Manager – Had been involved with establishing the original multiple project contracts strategy (MPCS) that established the contracts for *House*.
2. Glory Project General Manager (PGM) – Had also been involved with establishing the original multiple project contracts strategy (MPCS) that established the contracts for *House*, before moving to his position as Project General Manager for *Glory*.
3. *House* PGM #1 – Was the initial Project General Manager. Later moved to a corporate functional role.
4. *House* PGM # 2 – Took over from House PGM#1.
5. *House* Facility Manager – Reported to the PGM and was responsible for the delivery of all the systems associated with the offshore platform.

6. *House* Topsides Manager – Reported to the Facility Manager. Responsible for delivery of one element of the facility (including management of the contractors executing that system).
7. *House* Floating Systems Manager – Reported to the Facility Manager. Responsible for delivery of one element of the facility (including management of the contractors executing that system).

A number of the managers listed above were interviewed more than once (see Table 1). Two engineering contractors engaged with this project provided interviews with managers. Table 1 lists the in-depth interviews conducted.

Table 1. List of Interview Subjects by Company with Title.

Company	Position	No. of Interviews*	Date(s)
Sponsor	HOUSE Facility Manager	2 (R)	11/05/03, 03/04/04
Sponsor	HOUSE Topside Delivery Manager	1 (R)	11/05/03
Sponsor	HOUSE Floating Systems Manager	2 (NR)	11/05/03, 08/25/04
Sponsor	HOUSE PGM	1 (R)	11/06/03
Sponsor	GLORY PGM	2 (R)	11/06/03, 03/04/04
Sponsor	Offshore Supply Chain Manager	1 (R)	03/04/04
Sponsor	INDIAN PGM	1 (NR)	03/05/04
Sponsor	HOUSE PGM (initial)	3 (NR)	02/18/04, 03/25/04, 03/16/06
Sponsor	FROZEN Project Manager	1 (NR)	02/27/04
Sponsor	NORSE Commercial Manager	1 (NR)	04/08/05
Sponsor	NORSE Facilities Manager	1 (NR)	05/05/05
Contractor 5	NORSE PGM	1 (NR)	04/08/05
Contractor 5	NORSE Facilities Manager	1 (NR)	04/08/05
Contractor 5	NORSE System Delivery	1 (NR)	04/08/05
Contractor 6	Project Manager	5 (NR)	July, August 05
Contractor 2	Upstream Coordinator	1 (NR)	07/07/05
Contractor 2	Business Development Manager	1 (NR)	07/07/05
Contractor 4	VP Business Development	1 (NR)	08/03/05
Contractor 4	VP, Marine Pipeline Systems (PGM PARTY)	1 (NR)	08/03/05
Contractor 4	VP, Offshore Field Development	1 (NR)	08/03/05
Contractor 1	VP, Engineering	1 (NR)	07/12/05
Contractor 1	Chief Executive Officer	1 (NR)	07/12/05
Contractor 1	Chief Commercial Officer	1 (NR)	07/12/05
Contractor 7	VP, Engineering	1 (NR)	07/01/05
Contractor 7	Executive Vice President	1 (NR)	07/01/05
Contractor 7	Project Director	1 (NR)	07/01/05
Contractor 3	President	1 (NR)	07/11/05
Contractor 3	Business Development Manager	1 (NR)	07/11/05
Contractor 3	Vice President	1 (NR)	07/11/05
29 Subjects	**Totals**	**38**	

* (R) Indicated interview was recorded on audio tape, (NR) indicates interview was not recorded. Totals: 29 Subjects; 18 Contractors (7 firms), 11 Project Sponsors (1 firm). Interviews were conducted contemporaneous with projects in most cases. The NORSE project was the exception. For this project 2 interviews with project sponsor were conducted and 3 with project contractors.

Table 2. Map of Project Sponsor/Contractor Matching.

<table>
<tr><th rowspan="2"></th><th colspan="2">Sponsor</th><th colspan="3">Contractors</th></tr>
<tr><th>Project</th><th>Position</th><th colspan="3">Titles of Managers</th></tr>
<tr><td rowspan="4">Contemporaneous Projects</td><td>**House**</td><td>PGM#1,
PGM#2,
Facilities Manager,
Topsides Manager,
Floating Systems Manager</td><td rowspan="2"></td><td rowspan="3">*Contractor 1.*
CEO,
CFO,
VP Engineering</td><td rowspan="3">*Contractor 2.*
Bus Development Manager,
VP Engineering</td></tr>
<tr><td>**Glory**</td><td>PGM* (See "Miscellaneous" below)</td></tr>
<tr><td>**Indian**</td><td>PGM</td><td>*Contractor 3.*
CEO,
Commercial,
Project Delivery</td></tr>
<tr><td>**Party**</td><td></td><td colspan="3">*Contractor 4.*
Business Development, VP Engineering, Project Manager</td></tr>
<tr><td>Historical Projects</td><td>**Norse**</td><td>Commercial Manager,
Facilities Manager</td><td colspan="3">*Contractor 5.*
Project General, Facility, System Delivery</td></tr>
<tr><td></td><td>**Miscellaneous**</td><td>PGM* (Assisted in the development of the MPC strategy)
PSCM (Assisted in the development of the MPC strategy)
PGM (Frozen Project)</td><td colspan="3">*Contractor 6.*
Project Manager

Contractor 7.
Executive VP, VP Engineering, Project Director</td></tr>
</table>

Table 2 indicates how interviews were matched across projects. For example, for House, Glory and Indian, Contractor 1 and Contractor 2 worked on all three projects and multiple levels of each contractor were interviewed. Contractor 3, again across multiple levels to provide vertical data, was interviewed with respect to Indian only. There were no sponsor managers interviewed for Party, but Contractor 4 was interviewed across multiple levels etc.

4.5.4 Observation

Observations were typically made as a participant (Creswell 1998) and these observations served to both generate additional data and to validate existing work. Three types of activity (broadly defined) provided the context for observation. First, attending formal meetings with individual or teams of managers from the company to review and discuss the emerging theory. Second, participating in team projects, either as an ad-hoc consultant, or as a full time member, related to my research topic (see Table 3 for descriptions of the activities). Finally, an in-depth three month period, immersed in the sponsor company, where I worked as a staff member of the firm in developing alignment strategies.

Table 3. Activities providing observational data.

Activity	#	Team Size	Date	Format	Tasks
Research Review Presentations	1	2 Managers	02/27/04	Presentation and discussion	Present on-going research and emerging theory to experienced managers to solicit feedback and validate causal inferences.
	2	2 Managers (one manager from above)	03/31/04	Presentation and discussion	Present on-going research and emerging theory to experienced managers to solicit feedback and validate causal inferences.
	3	2 Managers (same group as above)	04/14/04	Presentation and discussion	Present on-going research and emerging theory to experienced managers to solicit feedback and validate causal inferences.
	4	5 Managers (managers previously interviewed)	07/28/04	Presentation and discussion	Present on-going research and emerging theory to some of the managers who had been interview subjects to solicit feedback and validate causal inferences.
Project Consultations	5	2 Managers	07/21/04	Telecon	Provide input to the development of a new contracting strategy for a particular market sector.
	6	4 Managers	07/28/04, 07/29/04	2 Day Workshop	Attend presentations on contracting strategy and observed discussions. Presented my research and emerging causal propositions for feedback and validation.
	7	1 Manager (Same manager as pervious telecon)	08/04/04	Telecon	Provide input to the development of a new contracting strategy for a particular market sector.
	8	5 Managers	08/18/04	1 Day Workshop	Attend presentations on contracting strategy and observed discussions.
Embedded Staff Position	9	2 Managers	June-August '05	3 Month on-site working engagement	Personally tasked with developing an "alignment strategy" as part of a larger contracting strategy project. Multiple meetings, discussions, presentations.
	10	7 Managers	June '05	Multiple work sessions	Attend presentations on major project "lessons learned" investigation and observed discussions.
	11	2 Managers	July-August '05	Multiple work sessions	Provide input to the development of a new contracting strategy for a particular market sector. Associated with the alignment strategy work.

4.5.5 3rd Party Interviews

In addition to the interviews and direct observations, data was gathered from documentary and archival sources as discussed earlier. A particularly valuable source of data was a comprehensive study carried out by an independent consulting firm into the most recent set of projects, some still on-going, managed from the sponsor's Houston office. This study focused on part of the same set of projects that I was investigating, and whose senior managers I had interviewed. I had access to the transcripts from 116 interviews with sponsor personnel and 15 with contractor personnel. This provided a useful data set with which to triangulate the observations I had gathered from my own in-depth interviews.

The 3rd party interviews were structured around "Performance Indicators", a set of informational categories (see Table 4 below), and for each category three questions were asked of the interview subjects:

1. "What was effective"
2. "What was not effective?"
3. "What recommendations do you have for future projects"

Table 4. Lessons Learned interviews: Number of respondents for each informational category.

Performance Indicator	Project Sponsor No. Respondents	Contractor No. Respondents
Contracting (Services)	109	15
MPCS	110	15
Front End Loading	105	15
HSSE Regulatory	109	15
Organization	114	15
Procurement (Material Management)	97	12
Project Drivers / Target Setting	113	14
Project Execution Planning	112	15
Quality	106	15
Risk Management	111	15
Additional Comments		
i. Communication	49	4
ii. New Technology	48	3
iii. Interface Management	39	3
iv. Project Services	98	15
v. Other	30	8
vi. Use on Next Project	105	8

4.6 Qualitative Analysis

Analysis of the data began during the observation phase in an iterative fashion, what Strauss and Corbin (1990) refer to as a “zig-zag” approach. Observations were coded using established qualitative methods (Strauss 1987, Strauss and Corbin 1990, Creswell 1998), and causal relationships developed. The posited relationships between categories suggested additional data gathering, either through follow up interviews, or a return to the primary sources for further analysis. The process followed is well summarized by Goulding (2002):

"The analytical process involves coding strategies: the process of breaking down interviews, observations and other forms of appropriate data into distinct units of meaning which are labeled to generate concepts. These concepts are initially clustered into descriptive categories. They are then re-evaluated for their interrelationships and through a series of analytical steps are gradually subsumed into higher order categories... ...which suggest an emergent theory"[27]

I do not intend to provide a full description of the process followed (i.e. a step by step description of the transcribing of interviews through coding and on to the development of concepts, categories and ultimately the theory). However, I will follow the suggestion of Glaser (1978) in presenting sufficient examples to facilitate an understanding of the analytic processes used.

4.6.1 Analysis of primary sources (my interviews)

Analysis of the interviews followed the methodology established by Strauss (1987), Strauss and Corbin (1990) and Creswell (1998). Interviews were either taped (with the subjects permission), or detailed notes were taken during the session. As soon as practical the tapes were transcribed into notebooks or into excel spreadsheets. The transcripts or notes were then analyzed line by line with a view to identifying key observations (words or phrases) that connect the particular account to the issue(s) under investigation (Goulding 2002). In my case this involved identifying observations associated with the challenge of building alignment. Coding of the transcripts first involved identifying

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[27] Goulding C., 2002, pp 74.

observations associated with distinct “concepts” (Strauss 1987, Goulding 2002). For example, the initial coding of interviews conducting with contractors in the U.S. resulted in 88 distinct observations being recorded and associated concepts identified. The observation below is an example.

> “Assurance of future work is the outcome of success, not the generator of it.”

This observation was recorded as being associated with the concept of “motivation”. Some observations contained multiple concepts and were recorded as such. For example, the following statement was made by the VP of Engineering for a contractor:

> “Don't use separate project team to direct work and procurement team to then manage contracts. Lack of alignment among drivers with difficult relationships and defensive behavior a result”

This particular observation was recorded as an example of the concepts of “divided authority”, “relationships” and “goals and drivers”. The context surrounding this observation was that decision making with respect to areas of project ambiguity was made difficult by having the formal contract administered by one part of the sponsor’s organization (procurement) while day-to-day technical decisions were made by another (project team). Not only were decisions separated by who had authority for capital expenditure versus technical performance, but by the drivers these distinct operational units had (cost minimization in the first case, project performance in the second). The observations that elucidated multiple concepts were critical in developing an understanding of interdependence amongst concepts.

Following the process of identifying concepts related to specific observations I began axial coding. This involved “moving to a higher plane of abstraction” (Goulding 2002) and developing an understanding of the dynamic relationships that existed amongst concepts. Through axial coding categories emerged. These categories have attributes (such as their intensity or weakness) which allows comparison of the same category across different projects, cases or LEP environments. For example the axial coding of the contractor interviews led to the abstraction of a number of concepts; scope, specification, goals and objectives into the category of “system architecture”. The category of system architecture thus has a number of attributes which can be dimensionalized. (e.g. “goals” may be fixed or shifting over time, clear or ambiguous etc). With these dimensions the category of system architecture is imbued with descriptive and theoretical power as a result of its ability to be used for comparative analysis.

Finally, and as per Goulding (2002), these thematic and descriptive categories were subsumed into higher order categories with explanatory significance. One such category is that of “Trust and Relationships”. Higher order categories incorporate lower order concepts, categories and their interrelationships. An example of an observation that supported the development of the “Trust and Relationships” category is shown below:

> "(Project A was) a success because (the Sponsor) was open - shared drivers/open communication"

The observation displayed the concepts of openness, communication, drivers and goals. These were among concepts that formed the thematic categories of system architecture (drivers and goals) and organizational design (communication). The interaction between these categories, via the mediator of openness (along with evidence from other observations) suggested the existence of the meta-category of "trust and relationships" as a framework.

4.6.2 Analysis of 3rd party interviews

Analysis of the extensive interviews conducted as part of the "lessons learned" investigation began with a review of the results of the survey conducted as part of this work. A 3rd party consulting firm, hereafter referred to as "PM Consulting" or PMC, administered survey questionnaires to both sponsor and contractor employees. Respondents were asked to rank, on a 1 to 5 scale, a number of project performance indicators (see Table 4). Each indicator was first ranked by "importance" from a score of 1 (not at all important), through 3 (somewhat important) to 5 (extremely important). Each indicator was then ranked by how "effective" the project had performed with respect to each indicator, again from 1 (not at all effective), through 3 (somewhat effective) to 5 (extremely effective). In addition, and as detailed in the Section 4.5.5, each respondent was asked to answer three questions with respect to the indicators:

1. "What was effective"
2. "What was not effective?"
3. "What recommendations do you have for future projects"

The responses were recorded in a set of interview transcripts.

My analysis of this large amount of data, approximately 350 pages, began with the survey results. PMC had taken the raw survey results and "averaged" the scores to come up with comparisons between contractor and sponsor perspectives of the project. For example, PMC reported that for the performance indicator of "risk management" the "average" contractor response was 4.5 compared with an "average" sponsor response of 4.6. Of course this "average" actually has no statistical meaning as the 1 to 5 scale is ordinal.

My first task was to review the original survey data. Fortunately, the report submitted by PMC included the respondent sample size for each performance indicator, both sponsor and contractor, along with the percent recording each score on the 1 to 5 scale. I was thus able to reanalyze the survey data with a view to identifying specific "areas" of the projects featuring divergent perceptions amongst respondents. It is important to note up front that the sample sizes for sponsor and contractor were substantially different (the number of sponsor respondents was up to 112, while the contractor respondents was as few as 8). This obviously limits the statistical validity of the analysis, however my use of the survey data was primarily as a pointer to direct further inquiry into the detailed transcripts.

The first set of data to be reviewed was the “Importance” criteria. I input the raw numbers into an Excel spreadsheet and then mapped the responses for the sponsors and contractors to the “radar” graph shown in Figure 15. This graph shows the percentage of respondents indicating a score of 4 (mostly important) or 5 (extremely important) for each respective performance indicator. As can be seen, the sponsors and contractors are in mostly solid agreement that each of the ten indicators is important (broadly defined). The one arguable exception is with respect to the MPCS.

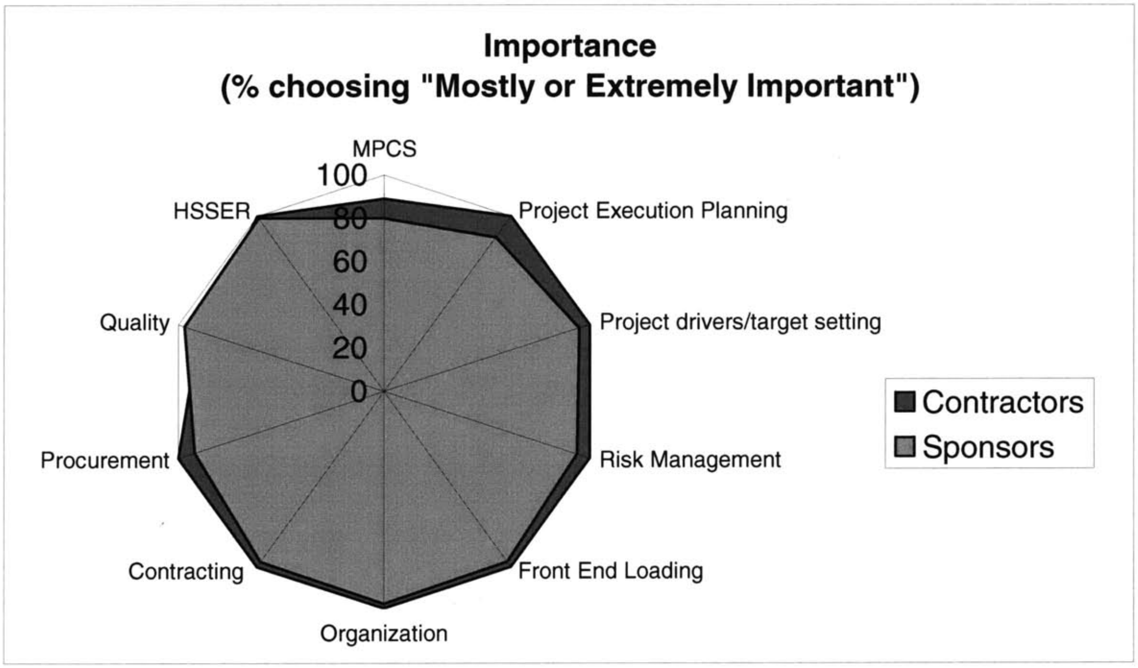

Figure 15: Contractor and Sponsor Perceptions of Project Attribute Importance

With almost all respondents choosing to rate the indicators as either mostly or extremely important I thought some insight may be gained by re-plotting the data with greater fidelity. Figure 16 is of the percentage of respondents choosing to rate each performance indicator as extremely important.

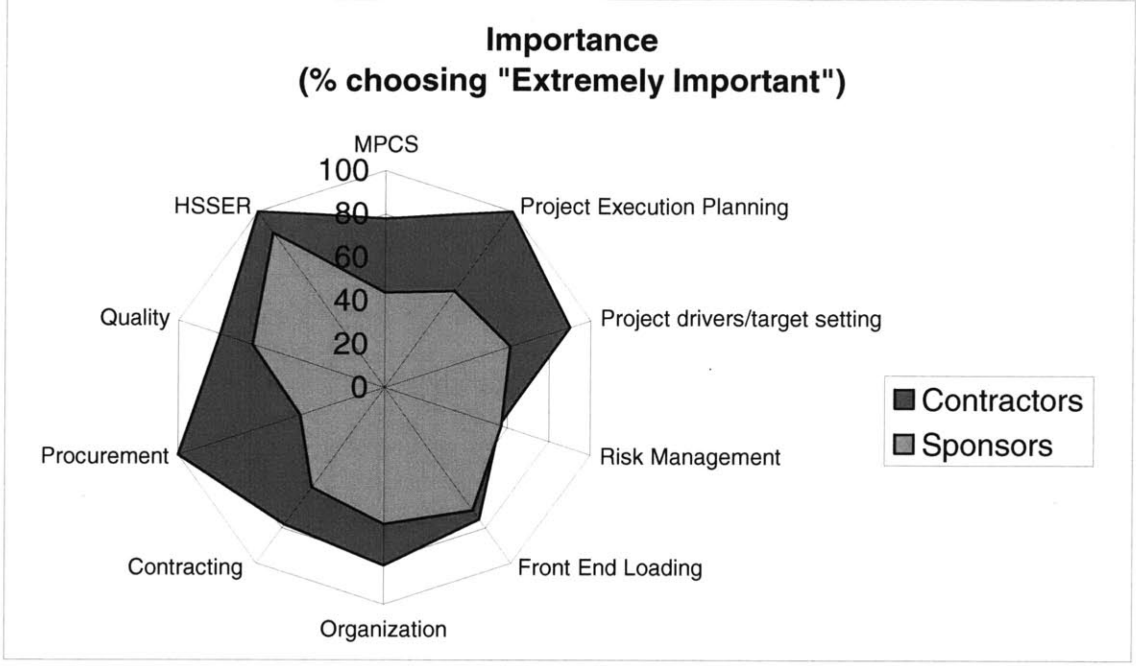

Figure 16: Contractor and Sponsor Perceptions of Project Attribute Importance – Refined Sample

This graph shows some marked differences between sponsors and contractors. For example, only 45% of sponsors thought that the MPCS approach to the set of projects was extremely important, compared with 78% of contractors. Similarly all the contractors (n = 11) viewed "Project Execution Planning" as extremely important while only 56% of sponsors agreed (n = 108). It is interesting to note that both sponsors (n = 117) and contractors (n = 15) considered HSSER (Health Safety Security Environmental Regulatory) as extremely important (88% and 100% respectively). This result is consistent with the oil and gas industry culture of safety and environmental awareness. This match between the survey responses and industry mental models and behavior perhaps can be taken as indicating that the rest of the survey results reflect the "reality" of the views held by sponsors and contractors.

The analysis of the effectiveness survey followed the same methodology. In this case the differences between sponsor and contractor perceptions were more marked. I plotted the percentage of respondents selecting effectiveness ratings of 3 (somewhat), 4 (mostly) or 5 (extremely) for each performance indicator. The results are shown in Figure 17. Again the performance indicator relating to the MPCS of projects showed very different effectiveness perceptions amongst contractors and sponsors. 65% of sponsors (n = 104) thought that the MPCS had been somewhat effective or better, while only 11% of contractors (n = 9) thought this. Again, caution needs to be exercised in reading too much into these numbers, but these results serve as an indicator as to where possible problems of misalignment might exist.

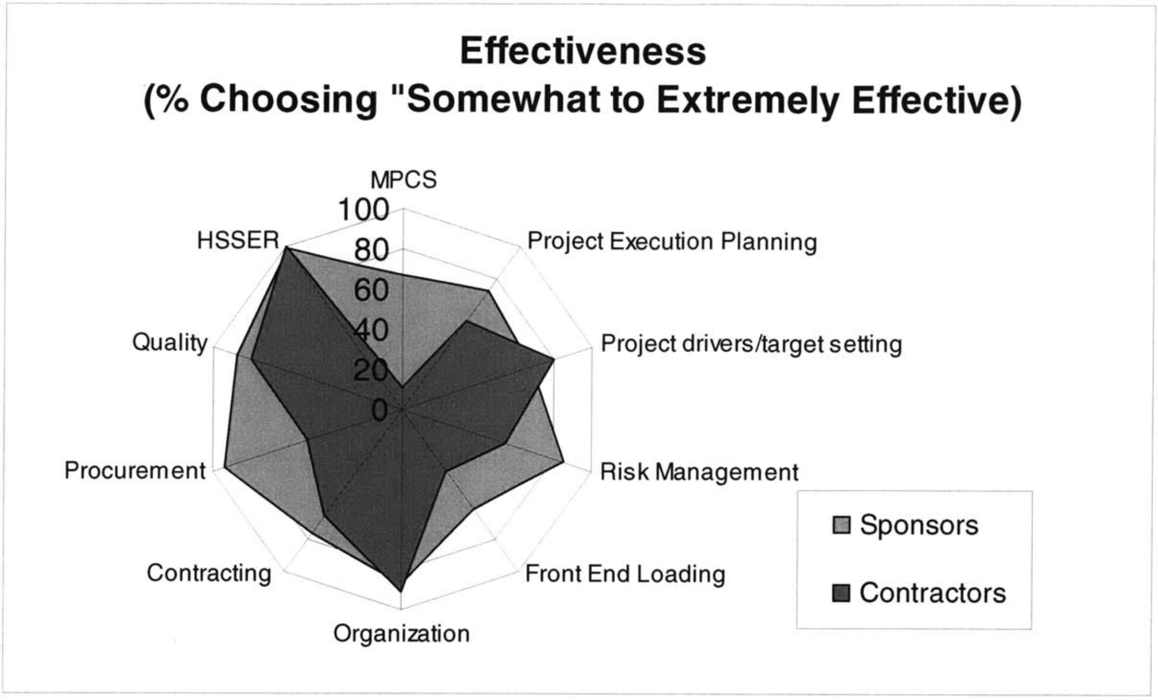

Figure 17: Contractor and Sponsor Perceptions of Project Attribute Effectiveness

I took the approach that evidence of the absence of alignment may tell us something about the conditions we need to encourage it. In other words, by focusing on where there appeared to be misalignment I might gain some insight into what policies or behaviors are needed to encourage alignment. With the results above serving as a pointer towards the appropriate place to enter the data I began the next stage of the analysis.

This involved reviewing the interview transcripts and sorting them in a manner consistent with the approach taken for the interviews I had conducted first hand. For example, the analysis of the apparent misalignment relating to the MPCS approach began by reading through the transcripts line by line and identifying key observations and comments made. These were then entered into an Excel spreadsheet. I finished with 170 entries from the sponsor transcripts and 27 from the contractor transcripts. Each entry was then categorized with respect to the concepts (Strauss 1987, Goulding 2002) associated with the statement. For example, the following statement was made by a senior manager from the sponsor organization:

> “(The) MPCS had no accountability or authority over individual projects”

This particular observation was recorded as “authority”. In a similar manner to my in-person interviews, some entries appeared to involve multiple concepts and were recorded as such. For example:

> “Did not achieve standardization goals because of no project buy-in with MPCS. Projects were not accountable for MPCS goals. Upper management did not “walk the talk’ after execute”

This particular entry was judged to contain several concepts. It was recorded as an example of the “motivation/commitment” and “goals and drivers” concepts as evidenced by the statement with respect to “no project buy-in with MPCS” in relation to the standardization goals. It was also recorded as an example of the “authority” concept in relation to the projects lack of accountability for MPCS goals. This process resulted in the recording of some 224 distinct observations from the sponsor transcripts and 34 distinct contractor observations in relation to the MPCS indicator. The observations which were coded with multiple concepts were critical in developing an understanding of how the categories were structurally linked. For example the following observation identifies the interdependence between a clear scope definition and contract performance:

> "Different levels of (scope) definition when contract set in place. Each of projects were at different stages, so difficult to get contracts to cover all scopes. Therefore contractors had reason for claims."

The next step was to group these various concepts around meaningful themes. These themes formed the basis of the descriptive categories of system architecture, organizational design, contract design, risk, metrics and incentives. Finally, these descriptive categories were then themselves subsumed into higher order categories. This analytic process was carried out independently of the analysis of my first hand interviews, but with reference to it. The importance of the 3rd party interviews was twofold. Firstly the transcripts provided a vast amount of data to support the building of my alignment theory. Secondly, and critically, the transcripts recorded interviews conducted with informants that I had interviewed previously. This allowed for validation via the constant comparison method (triangulation) between observations drawn from my interviews and that of a neutral third party.

4.7 Diagramming

In addition to the transcribing of interviews and coding of responses I employed a number of other well established techniques from the grounded theory building methodology such as the use of memos and diagramming (Strauss 1987, Strauss and Corbin 1990, Cresswell 1998, Goulding 2002). Diagramming was particularly useful in this environment and was employed in the following ways:

1. Diagrams were used to capture relationships between actions or behaviors described by interview subjects, or revealed in the literature.
2. Diagrams, particularly once individual instances of relationships had been added together to create causal loop diagrams (Sterman 2000), were used as a communication tool with practitioners. This allowed validation of concepts emerging from the data.
3. The causal loop diagrams then served as the building blocks for the development of a formal model (Sterman 2000).

As described by Sterman (2000), causal diagrams are useful for "eliciting and capturing the mental models of individuals or teams"[28]. Strauss (1987) recommended the use of graphic methods as "they can give visualizations of what's going on with the phenomena under scrutiny"[29]. By way of example I shall describe the process by which observations recorded from the transcripts were captured by diagramming, and ultimately developed into causal relationships.

One comment made by a senior manager from the sponsor team was that:

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[28] Sterman J., 2000, pp 137.
[29] Strauss A, L., 1987, pp 143.

> "*House* had too many people. This created more interfaces, delayed decision making and ultimately (led to more) variation orders"

This comment (and others like it) were captured in the casually linked structure shown below.

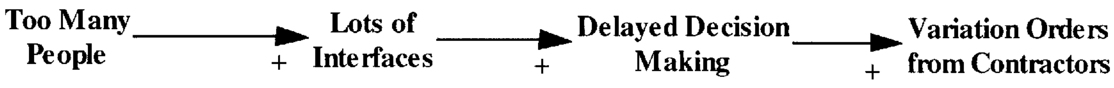

Figure 18: "Too much oversight leads to delays and changes"

This observation was echoed by numerous contractors. For example:

> "Minimize size of client teams. More people means more opinions to reconcile, more time spent coordinating"

Thus one issue that appeared in multiple contractor interviews, and indeed in numerous sponsor interviews, was associated with the sponsor's use of "too many people" for oversight. This comment came in many flavors but included a number of key concepts:

- The use of large numbers of sponsor's staff as oversight displayed a lack of trust.
- Large numbers of sponsor staff increased the number of contradictory directives from the client.

- As projects appeared to be falling behind in performance, sponsors added staff to the project. This slowed decision making.
- The larger the number of "sponsor" staff, the more likely that these folks had different drivers (either organizationally – Commercial versus Operational), or personal (Agency folk versus "staff").

These various comments were captured in a number of similar causal relationships that ultimately were captured in the causal diagram shown below.

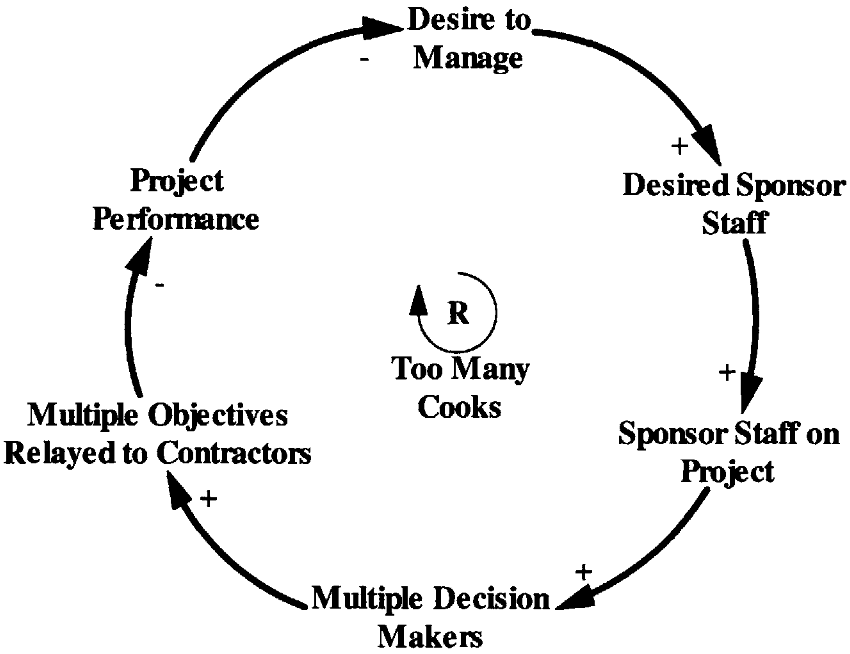

Figure 19: "Too many cooks can spoil a project"

It was clear that while optimal performance indicates that efficient project execution means "right sizing" the project team, when problems emerged (as they do an all projects) an initial response was to commit larger resources to the project. This, in some cases at least, made things worse in the short run.

In addition to capturing information relating to causality within and amongst categories, the diagrams were frequently used as a communication tool with interview subjects and other practitioners. For example, the following causal loops linking revenue security for the contractor to project relationships, commitment to communication and project performance, were discussed on multiple occasions with teams of practitioners in formal and informal settings. Their agreement with (and experience of) the central mechanisms highlighted in the diagram provided validation that the theory was at least plausible.

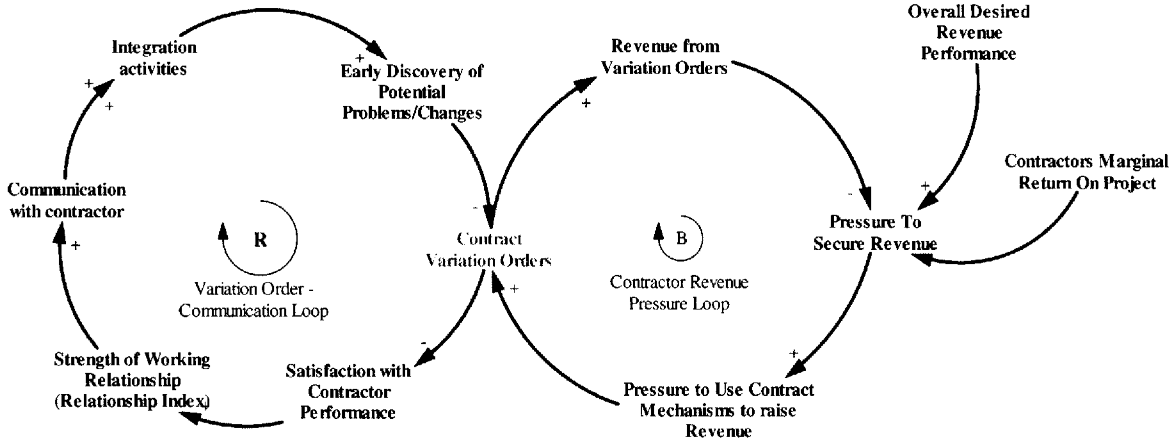

Figure 20: Variation Orders are a Linking Mechanism

4.8 Formal Model Building

The final use to which I put causal loop diagrams was as building blocks for the formal dynamic simulation model. As described above in the methods section, the development of a formal model provides a useful analytic tool for theory development. Formal dynamic models, like all simplified abstractions of reality (economic models, design structure matrices, network graphs) have limited utility in being able to "prove" a theory. My model is no different. However, like these other tools, a formal model allows for the development of qualitative predictions, and the exploration of the effects of explicit assumptions, that enhance theory development.

Building very rich models may offer greater fidelity with respect to the reality, however as stated by Gibbons "adding richness and realism to these models will certainly change the models' quantitative conclusions, but the major points we derive from the simple models will still be part of the package of qualitative conclusions from the richer models"[30]. Gibbons was discussing economic models, but the statement is equally true of dynamic models. Sterman (2000) points out "all models are wrong", but while this is true and thus "verifying" a model is essentially impossible in the sense of demonstrating the "truth" of the model, he also advocated that modelers "seek multiple sources of contact between the model and reality by drawing on many sources of data and a wide range of tests"[31]. I have endeavored to follow his advice by drawing upon established models,

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[30] Gibbons R., Lecture Notes 1, http://web.mit.edu/rgibbons/www/LN_1_Agency_Theory.pdf., pp 2.

[31] Sterman J., 2000, pp 850.

observations from informants and archival documentary evidence, as well as by presenting the model and the derived results to practitioners.

I built and analyzed a simple project model in order to explore the basic assumptions captured in the causal loops shown in Figure 20 above. Building the model forced analytic rigor into the process of understanding the causal mechanisms elucidated from the qualitative method. It is necessary to understand what variables represent "stocks" in the system, how they are affected by mediating variables and what "flows" cause these stocks to increase or decrease. The structural mechanisms that link these variables then are made concrete and can be tested against observations made in the field.

The model was able to replicate, to the first order, the behavior of simple projects operating under zero-sum contracting assumptions as well as the more complex non-intuitive behavior of complex projects. The results were presented to practitioners for validation. The process of building a formal model frequently provides as many insights as does the analysis of its output (Sterman 2000); this was the case in this instance. The next chapter presents some results from the model and discusses the qualitative conclusions that can be drawn from it (model formulations are in the Appendix). These conclusions are then built into the developing theory in the following chapters.

5.0 Results (The Challenge of Alignment)

Analysis of the first-hand interview transcripts, 3rd party interview transcripts, secondary documents and the observations made in the field revealed that alignment is generated by practitioners (and firms) knowing what is being asked of them (and of others) and of having a solid working relationships (among firms) through which they deal with remaining uncertainties. I frame these as: (1) the search for shared understanding and (2) the search for trust. The two antecedents of alignment cannot be specified in contractual language but need to be "built" through interactions among the firms. As such I sought to identify the factors that shape the inter-firm interactions. The analysis resulted in the identification of six factors that deliver the practical instantiation of (1) shared understanding and (2) trust that enable the generation of alignment. These six factors can be thought of as the design variables for alignment. They are:

1. System architecture
2. Organizational design
3. Contract design
4. Risk
5. Metrics
6. Incentives

5.1 Alignment among the Firms of a Large Engineering Project.

Alignment in the context of LEPs can mean quite different things to different stakeholders. For example, one manager from a sponsoring organization stated, only slightly tongue in cheek, that alignment with contractors is achieved when "they act as we want them to". Another stated that alignment was when "we all agree on, and buy into, the objectives". One manager put it simply this way; "Alignment is when the contractors act as we would if we were doing the work". While there were almost as many alternative definitions offered as interviews conducted one assumption was almost universal; that achieving alignment contributed to project success. The existence of alignment (or lack thereof) was frequently cited by interview subjects as being a driver of project success (or failure).

> "Building long-term project execution success requires alignment with our contractors" (Sponsor Contracting Report)

It is worth restating at this point the definition of alignment that I have adopted from the MIT Working Group on Alignment. Alignment is defined as the patterns of interaction within and across inter-dependent stakeholders that serve to advance the separate and the collective interests of these stakeholders.[32] The following sections highlight the patterns of interaction that form alignment and the specific project attributes that shape these patterns.

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[32] Cutcher-Gershenfeld J., Moses J., 2005.

5.2 Searching for Shared Understanding

Consider a project that is completely known and understood at the outset. Every detail of what needs to be done, exactly what the finished product will look like and how it will perform is understood with certainty. All of this is captured in extremely detailed design guides, specifications and engineering drawings. The project sponsor will bid the job to the market place, receive a quote and then verify that the contractor follows the design specifications. Let us also assume that the contractors' actions are observable and verifiable (some trivial projects may meet these criteria – building a garden wall for example). In a case such as this "understanding" is provided by the detailed specifications. The home owner then monitors the contractor to ensure that the work is carried out in accordance with the specification. If the specification has no ambiguity then the search for understanding is limited. Everything that home owner wants from the project is specified and both the contractor and sponsor (home owner) understand this.

Large engineering projects clearly have little in common with the scenario detailed above. They emerge over time and, as described in Chapter 2, feature uncertainty and ambiguity with respect to most of their important elements: the performance desired from the product system, the form it will take, the various constraints to be dealt with, the tasks to be carried out, and the resources needed. Firms working together on LEPs are engaged in an effort to ultimately resolve these ambiguities and in doing so each firm selects from among alternative courses of action and possible outcomes. When choosing from amongst alternatives individuals (and firms) need a frame of reference to guide the choice

(March and Simon 1958, Kahnemen and Tversky 1979, 1986). My research highlights four domains in which firms appear to "search for understanding" to construct compatible frames of reference:

- Understanding the project objectives and constraints
- Understanding the project task requirements and boundaries
- Understanding project uncertainty and coupling
- Decision making and heuristics

5.2.1 Understanding of Project Objectives and Constraints

Many practitioners, both contractors and sponsors, stated that alignment begins with understanding the objectives and drivers of a project. Confusion with respect to the project goals was frequently cited as a problem; for example, shifting midway through a project from a focus on cost control to schedule (as reported by a project manager for a contractor):

> "First oil[33] became a key driver, which conflicted with costs"

As contractors attempt to build knowledge and drive ambiguity out of the project they are constantly making choices; about the appropriate technology, process, procedures etc. These choices need to be framed by an expectation of what the project sponsor "prefers" (e.g. the most sophisticated technology versus a cheaper but less efficient solution) and

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[33] In this case "first oil" refers to the sponsor's desire to have the project completed as soon as possible (i.e. schedule is now more important than cost) in order to achieve initial production.

any ambiguity around the drivers can lead to choices that the sponsor, or other contractors impacted by that choice (and who may have had a different understanding of the preferred outcome), are dissatisfied with. This results in time being spent in negotiation, adjustments and change.

Sponsors also stressed the need for establishing clear drivers. When asked "what was not effective about the project" a senior manager on the *House* team offered the following:

> "Not all drivers were understood" (Well Systems Team Lead)

The sponsor team also struggles with determining the "right" choice from the alternatives being presented and managers (and staff) responsible for different aspects of the project may have contradictory views of what is optimal. As the project unfolds, and efforts are directed towards reducing ambiguity, they also search for understanding of the projects objectives.

5.2.2 Understanding Task Requirements and Boundaries

Along with a clear sense of the projects drivers, definition of what the project is to physically create was also offered as crucial to building alignment. A manager for one of the contractors interviewed put it succinctly:

> "Good alignment begins with a clear scope of work"

The "scope of work" typically refers to the project's performance specification (what the product system is supposed to "do"; its function or intent), the description of the product system's form (what it actually is) and the boundaries of the contractor's responsibilities with respect to these specifications (what the contractor is to do). A clear scope is about limiting uncertainty and ensuring that the boundaries among subsystems, and the contractors responsible for those subsystems, are explicit and understood. Echoing the observation about project drivers, many informants noted that ambiguous scopes result in poor project performance. As before, in responding to the question "what was not effective about the project?" both contractors and sponsors highlighted a lack of understanding of project requirements.

> "Scope was not defined in a timely manner" (Contractor Project Manager)

> "Scope definition was poor, leading to changes" (Facilities Project Services Manager)

It appeared to be universally understood that project success is strongly correlated with clearly defined scopes of work.

5.2.3 Understanding Uncertainty and Coupling

Having a well defined project at the outset certainly helps in delivering improved project performance (Merrow 2003, Clark and Wheelwright 1993, Cooper and Klienschmidt 1994, Cleland 1990, Ulrich and Eppinger 2000). However, LEPs feature significant ambiguity (Browning 1998, Miller and Lessard 2000, Flyvbjerg 2002). Firms therefore need to understand where uncertainty resides and how the outcomes of decisions made with respect to that uncertainty propagate through the project; how subsystems and contractors' scopes are coupled. Failure to do so, and in particular, to organize the contracts and organizations to deal with uncertainty that spanned boundaries was lamented by sponsors and contractors alike.

> "We were blindsided by scope changes because (the sponsor) worked in silos" (Contractor Project Manager)

> "Contracts in place for MPCS did not recognize project and MPCS complexities; using one yard meant changes to one project impacted others; it's important to recognize the complexity of design" (Sponsor Engineering Manager)

Understanding that it is difficult to recognize in advance all the instances of coupling among firms and subsystems, many practitioners highlighted the importance of building robust processes for managing change across boundaries. One manager from a contractor stated it simply but strongly:

> "Interface management is the key"

Practitioners generally agreed that alignment among firms requires awareness of the complexity of system interdependence, and the need to build understanding around these interfaces, particularly in light of incomplete scope definition.

5.2.4 Decision Making and Heuristics

The final domain in which firms search for shared understanding is with respect to decision making: how decisions are made, who makes them, and on what basis. My research indicates that genuine alignment is founded on practitioners knowing how decisions are made and by whom. When the outcomes of decisions can impact multiple firms it appears important that the decision making processes are not opaque.

> "While drivers were made explicit, it appeared that unspoken drivers were steering decision making" (Contractor Manager)

> "It was very difficult to know who was the decision maker" (Sponsor Manager)

The comments above reflect discomfort with ambiguity around decision making, both in terms of the heuristics being employed, and which individuals were making the decisions. Sponsors and contractors wanted to have clarity in the decision making process and expressed frustration when it wasn't present.

> “The sponsor had a very slow decision making process (it appeared to be consensus driven). This slowed progress, added schedule pressure and damaged morale” (Contractor Vice President)

> “Empower the sponsor project manager and project engineers to make decisions” (Contractor Project Manager)

5.3 Searching for Trust

The search for understanding was accompanied by the search for “good relationships” among firms. In addition to shared understanding, alignment is founded on firms and practitioners being able to base their interactions on trusting relationships and the assumption of “fair” dealings with each other and . As one manager for a contractor put it:

> “Alignment means a good relationship, and that begins with respect and mutual trust”

Trust among individuals, and indeed firms, has been documented as delivering superior performance (McAllister 1995, Dyer 1997, Zaheer et al 1998) and it is reasonable to expect this outcome to hold for LEPs. The intuitive sense of trust as an important element of alignment, displayed by the comment above, was observed across sponsors and contractors. The search for trust was multifaceted and involved establishing the following:

- The other party's competence and reliability
- The consistency of their behavior
- Their "fair" play with respect to opportunism
- Evidence of a reciprocal approach

5.3.1 Competent and Reliable

It may appear to fall under the rubric of "calculative trust" (Williamson 1993) to begin the search with an assessment of the other party's competence and reliability. However, in the reality described by my informants, alignment does require confidence in the other party's abilities. Practitioners described failure to meet acceptable standards in terms of having the appropriate skills or resources as damaging to relationships and alignment. For example:

> "The sponsor and contractor Z were never aligned during project development. The contractor didn't have the background, resources or tools needed"

The firms' search for trust includes a search for project participants that can deliver on what they promise. Evidence to the contrary, in the tightly coupled environment of LEPs, means mistakes or misrepresentations can strain multiple relationships.

> "Contractor C took on work outside of their core competencies. It was a mistake to give them all that work and it led to strained relationships with both contractor C and contractor T (whose scope interfaced with C)" (Sponsor Project Manager)

5.3.2 Consistent Behavior

Along with reliable and competent behavior, firms sought consistency of approach towards inter-firm dealings. This facet of building trust was explicitly mentioned by multiple informants across a number of distinct realms. When firms appear to act in an arbitrary fashion trust, and relationships, suffer. The following comment from the Vice President of a contractor exemplifies the idea:

> "We do lots of work with the sponsor, yet each time we are asked to bid, the pre-qualification requirements appear to be onerous and seemingly arbitrary. The sponsor has institutional amnesia."

5.3.3 Non-opportunistic Behavior

Firms build trust by displaying behavior that is not opportunistic. A common complaint (from both sides of the sponsor-contractor divide) was that when firms were able to, they would exploit market imbalances (if they existed), or instances where the ability to observe the others' actions was low, in preference to establishing relationships. For the sponsors this took the form of feeling that contractors exploit shortage of skills, or peak demands, to foist substandard personnel onto their projects. For the contractors it was the belief that sponsors act as price setters and use the bidding process to manipulate the market:

> "The sponsor forces competition between firms that are not risk or resource equal. Don't ask us to bid if we are up against a "ma & pa shop". It shows a lack of respect."

There was general agreement though that equitable relationships, (resulting in trust), are preferred and are built by firms acting in a non-opportunistic manner. The instantiation of this belief was the view that "fair" relationships were evidenced by firms "leaving the contract on the shelf". This common expression was indicative of the shared perception that as contracts are incomplete both parties are able to "use" them to their advantage in a narrow sense, but doing so irreparably damages the relationship.

5.3.4 Reciprocal Behavior

The final element that practitioners were looking for in trust based interactions was evidence that their efforts to build trust were being reciprocated by others. Evidence of reciprocity (or the lack thereof) took many different forms. A common complaint among contractors was that sponsors use more oversight staff than (they perceived) necessary displaying a fundamental lack of trust.

> "The sponsor provided more staff than needed, again, a trust issue" (Contractor Manager)

In a similar fashion the sponsors approach to resolving the costing of decisions seemed to betray a lack of trust.

> “With a procurement (rather than trust) based approach, the focus shifts to money around each decision irrespective of scale. We say $100, immediate response is $99.96. This damages trust, respect between teams.”

Finally, the very way in which the relationship begins – at the point of negotiating the contract – was seen by some practitioners as the ideal point to establish a trust based approach. Clear evidence of a lack of respect, such as attempts by the sponsor to force onerous contract liability terms onto the contractor, inhibited the all important quest for trust.

5.4 The Six Factors

The search for understanding and the search for trust combine to deliver alignment among firms. This is shown in Figure 21.

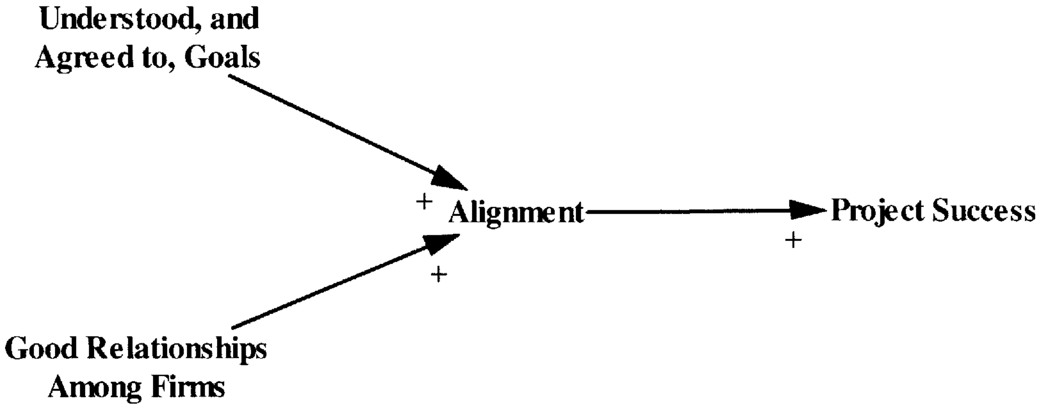

Figure 21: Simple Alignment Model

However trust and understanding cannot simply be specified in the contractual documents, nor purchased by paying a higher rate for it. They need to be “built” through the interactions that take place among the firms; interactions that facilitate the sharing and creation of knowledge and also provide the opportunity for firms to establish their “trust worthiness” (Weick 1993, Weick and Roberts 1993, Weick et al 2005, Zaheer et al 1998).

I sought therefore to identify the means by which interactions were established and shaped. My analysis revealed six factors that serve as “design variables” in shaping the content and process of inter-firm interactions. The factors are: the product system architecture, the organizational design (across and within firms), the contract design, risk, metrics and incentives.

5.4.1 System Architecture

Many practitioners referred to alignment being based on clear scopes of work, objectives and constraints as discussed above. This sense of an explicit and comprehensible set of project characteristics is very much akin to the idea of well described system architecture[34]. Maier and Rechtin (2002) define architecture as:

> "The structure (in terms of components, connections, and constraints) of a product, process, or element."[35]

Professor Crawley in his MIT course on system architecture offers the following definition of architecture as:

> "The embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of interfaces among the elements and with the surrounding context."[36]

System architecture as an alignment factor is primarily involved with establishing the "components, connections and constraints". The attributes of system architecture create a set of agreed and understood "facts" about the project. These attributes are:

- The performance specification (what the systems is supposed to "do"; its function or intent)

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[34] I limit the idea of system architecture in the context of LEPs to mean the product system architecture: the arrangement of the physical and software components of an offshore oil and gas field, their intended performance requirements and the constraints placed upon achieving these requirements.

[35] Meier M, W., Rechtin E., 2002, pp 288.

[36] Crawley E., 2003.

- The description of the system's form (what it is)
- The drivers/constraints of the project (e.g. schedule, cost etc)

System architecture is an important factor in establishing the degree of ambiguity in the project. The specifications (either a performance specification – what the system does, or a form specification – what the system is) helps to define what is known and what is unknown. The specifications establish the degree of novelty in the system, either in terms of new technology, or the novel application of existing technology. The specifications/scope for the entire system is then packaged into discrete subsystem specifications/scope to be assigned to the various contractors. The partitioning of the system is an architectural choice and establishes the interfaces amongst the subsystems that need to be managed. Thus the question of what is known and unknown expands to include "known to whom?" What may be explicit and known to one firm may not be to another (i.e. if it falls outside of their scope, even if it may affect them).

5.4.2 Organizational Design

Organizational design is concerned with the arrangement of staff, their number, responsibilities, reporting relationships, decision making processes and locations that define the project enterprise. It is a grouping of a number of key concepts. The interview transcripts contained many observations with respect to issues of communication, resource allocation and decision making or authority. For example:

> “Behaviors between projects could have been better - too much "me". Who had control of, and what responsibilities for, various deliverables?” (Sponsor Facilities Manager)

LEPs exhibit many of the attributes used to describe an organization in classic organizational theory. As Perrow (1986) describes, “organizations are tools designed to perform work”[37] and feature bureaucratic rules, authority relationships, and allocation of resources to achieve specific ends.[38] Lawrence and Lorsch (1967) define an organization as “a system of interrelated behaviors of people who are performing a task that has been differentiated into several distinct subsystems, each subsystem performing a portion of the task, and the efforts of each being integrated to achieve effective performance of the system.”[39] Thought of this way, the design of the project organization then becomes a critical factor in shaping the efficacy of operation; how well the various units of the project organization (the distinct firms) work together. The organizational design factor has the following attributes:

- Coordination and communication
- Allocation and choice of resources
- Allocation of responsibility and decision rights (including decision process).

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[37] Perrow C., 1986, pp 13.

[38] This description of an organization is consistent with the classical description offered by Weber (1947) of bureaucratic forms of organizations. If we consider alternative conceptions of organizations, such as Trist (1981) of organizations as socio-technical systems or March and Simon’s (1958) decision making paradigm, we would still conclude that the project enterprise is an example of an organization in the large.

[39] Lawrence P, R., Lorsch J, W., 1967, pp 3.

These attributes shape inter-firm interactions in a number of ways. First, consider the selection of project staff location. One senior manager from a contractor, in discussing the factors that contributed to the success of the Norse Alliance, pointed out that the client and he had formed a "joint project management team", and had shared office space and a single secretary. This he felt "sent an important signal" about the alliance "team" and management expectations about the co-located engineering teams working together. Various researchers have pointed out the importance of co-location in creating an environment for the rich communication needed in complex projects (Allen 1977, Keller 1986, Van Den Bulte and Moenart 1998).

Of course, with large projects it is usually impossible to co-locate the project organization as the firms that form it are typically spread across the globe.[40] This creates obvious problems for achieving easy communication across the project team (Jarvenpaa and Leidner 1999, Maznevski and Chudoba 2000, McDonough et al 2001). The use of synchronous and asynchronous electronic communication may mitigate the physical separation to some extent (Van Den Bulte and Moenart 1998, Maznevski and Chudoba 2000, McDonough et al 2001). It therefore becomes critical for the project sponsor to consider the effects of physical separation amongst the firms on the project and to design appropriate organizational mechanisms as mitigation. As one manager from the project sponsor put it:

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[40] The Indian project had teams working in Houston TX (5 locations), Morgan City LA, Sweden, Korea, Holland and Singapore. This is typical for projects of this scale. The BTC Pipeline project had contractors working in Norway, Sweden, Holland, France, Italy, Turkey, Dubai and Azerbaijan.

> "Project organizations on bigger projects tend to get into silos so interface management is needed."

The use of organizational design as a tool for facilitating group interactions has been supported by numerous researchers (Van Den Bulte and Moenart 1998, Maznevski and Chudoba 2000, McDonough et al 2001). Van Den Bulte and Moernaert (1998) state that "organizational procedures and systems can compensate for some of the negative aspects traditionally associated with locating some units apart from the rest of the corporation."[41]

The use of design reviews and other formal elements of a stage-gate product development process not only serves to monitor performance, but also assists in developing informal communication patterns (Maznevski and Chudoba 2000). Project sponsors also have a significant say in shaping what artifacts are used to assist communication amongst the teams. As Carlile (2004) points out, "the effectiveness of an outcome at a pragmatic boundary is based on the capacity of the common knowledge and the ability of the actors involved to use it."[42] Stating it more simply, the sponsor can choose what format information is transferred in and when, what engineering design packages will be used to represent the system, and what detail they expect from contractors at each design review. In doing this they can shape how well the various contractors interact.

Organizational design can also be viewed from the perspective of Jensen and Meckling (1990) who argued that it involves selecting the location of decision rights with respect to

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[41] Van Den Bulte C., Moenaert R, K., 1998, pp S15.
[42] Carlile P, R., 2004, pp 565.

the knowledge required by the organization. In the context of LEPs we can frame the decision rights issue by considering two questions. First, how much authority over project ambiguity does the sponsor transfer to the contractors via the contracts? Second, for the rights retained by the sponsor, which resources hold those rights?

I will discuss in detail the alignment issues associated with selection of various contract forms, and resultant distribution of decision rights, in the next section. However I will make one point now; the allocation of sponsor resources and their perceived (or real) authority to make decisions must be consistent with the contract type used. For example, it does not build trust if the sponsor pairs the award of a lump-sum contract (with its inherent transfer of decision rights to the contractor) with a large team of engineers more suitable for managing a reimbursable contract.

The allocation of decision rights within the sponsor also shapes inter-firm interactions. A commonly stated frustration amongst contractors was that in dealing with the sponsor they often saw multiple "faces" from the client. For example:

> "We (a contractor) had to deal with five sponsor teams fighting with each other." (Contractor Manager)

The organizational design factor allocates the responsibilities and decision rights of staff, their locations and number and establishes the communication protocols and process. But unlike a traditional organization, LEPs face the challenge of creating the above across the boundaries of legally distinct firms. It is through the contracts that substantial elements of the organizational design are enacted.

5.4.3 Contract Design

LEPs involve more than one firm in the development of the product system; its detailed design, fabrication and final assembly of the product. The mechanisms used to bring separate firms together for these projects are formal contracts. The contracts establish the scope of work for each contractor and the commercial terms entered into by both parties (their rights and obligations). Contracts are used by sponsors to access the required resources (technology and knowledge) from the market place to deliver the project[43]. The attributes of contract design are:

- The contract form (from turn key to reimbursable)
- The contract scale (multiple projects or one off)
- The contract award process (negotiated vs. bid)

Contract form can be described as a continuum from a fully reimbursable to a turn-key contract. Fully reimbursable contracts derive their name from the fact that contractors are reimbursed by the sponsor for their costs plus an agreed profit. At the other extreme are turn-key or lump-sum contracts. Under these arrangements the contractor nominates an inclusive price for completing their scope of work. All work is done for that agreed price

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[43] This, on the face of it, appears to be a text book example of the "make-buy" tradeoff (Fine and Whitney 1999). The oil producing firms retain expertise in finding, producing and managing the hydrocarbon reserves but rely one the market place to provide the necessary engineering skills to develop the technology that they then employ to extract the hydrocarbons.

and the contractor's profit is a function of how efficiently they execute the work. Of course, as we discussed earlier, all LEPs are somewhat ambiguous so lump-sum contracts contain provisions for changes to be made as the work progresses and for the costs of these changes to be added to the agreed price.

From my interviews and supporting documentary evidence, it appears that practitioners believe the implications of these contract types are as follows:

- Lump-sum contracts transfer the most risk away from the sponsor and to the contractor. This assumes that the project is well defined and that once a contractor agrees a price, any unforeseen challenges (provided that they occur "within" the scope of work) and resulting costs are absorbed by the contractor.
- Reimbursable contracts[44] are the most flexible when details of the project are uncertain. They consequently run the risk of cost escalation but the contractor's profit margin (and hence reward) is constrained by the terms of the contract.

These assumptions are captured in Figure 22 sourced from a project sponsor:

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[44] In Figure 22 a form of contract similar to reimbursable is shown. This is the Bill Of Quantities (BOQ) or Rates contract. This type of contract establishes the rates or prices for quantities/types of work to be carried out (e.g.$ per ton of mild steel). A fully reimbursable contract has the contractor passing on all costs to the sponsor with a fixed percentage mark up while a BOQ/Rates contract has pre specified rates that are fixed.

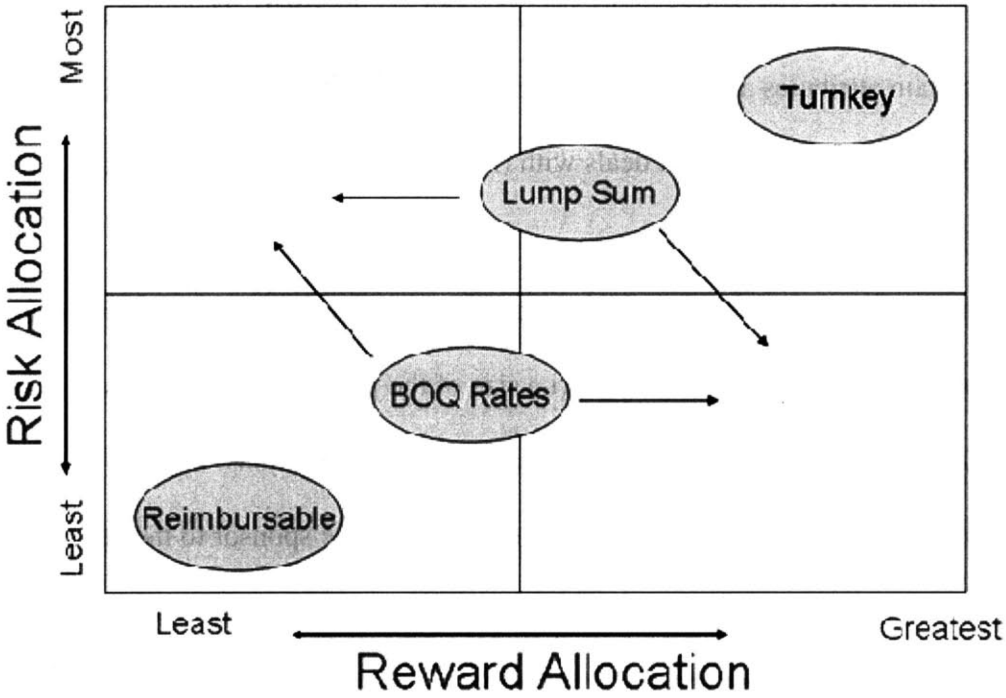

Figure 22: Risk/Reward Allocation to Contractor by Contract Type

The influence of contract design on inter-firm interactions begins with the process used to award contracts, for example through the use of coherent and transparent qualification procedures:

> "Tender requirements are inconsistent. Need a level playing field." (Contractor Business Development Manager)

The process commenced above eventually leads to the award of a formal contract, and the type of contract used can have significant impact on interactions amongst firms. Contract design, as a factor influencing alignment, is best understood in terms of "fit" with the environment in which the contract will be used. I use the term fit in a manner akin to that of contingency theory (Lawrence and Lorsch, 1967). The contract type, having certain attributes associated with flexibility, risk allocation etc, should be matched to the environmental variables it deals with (Pich, Loch and De Meyer, 2002).

Consider the different forms of contract. Each will specify a scope that has variation in its degree of ambiguity, novelty and scale (i.e size of the job proposed in terms of man-hours of work). Each will establish the commercial terms and conditions. Implicit in each contract is a transfer of decision making authority from the sponsor to the contractor. A reimbursable contract retains most authority with the sponsor as the contractor acts as a consultant. A turn-key contract transfers most authority to the contractor for selecting the way in which the contract is satisfied, subject to assurance activities by the sponsor.

The "environment" is comprised of the following attributes: Firstly, the actual degree of ambiguity, novelty and scale that exists in the system architecture of the project. Secondly, the capability of the contractor, in terms of his knowledge, technology and capacity (human assets, technical assets) to handle the scope and attendant uncertainty (including any potential downside financial consequences). Thirdly, the sponsor's organizational capability for administering/directing the activities associated with the contract. In addition the environment includes the sponsor's, and the contractor's, drivers. And finally, the environment includes the interdependencies that exist as a function of the system architecture amongst the scopes that have been parsimoniously distributed to distinct contractors.

The research uncovered multiple instances of a lack of fit between the contract type and the environment. This lack of fit shaped the response of the firms affected. For example, a number of managers, from different contractor firms, suggested that the use of reimbursable contracts when firms are set up to manage lump-sum contracts can have negative consequences for performance:

> "(We) prefer EPC (a form of lump-sum contract). Reimbursable contracts allow (almost encourage) the client team to continue to optimize design and make changes, causing delays and increasing costs." (Engineering Service Contractor Manager)

Of course the issue is not specifically around not using reimbursable, but rather the use of the appropriate contract. As one manager put it:

> "Use the contracts that contractors are familiar with." (Contractor Vice President Engineering)

Another example of an opportunity for lack-of-fit is between the degree of system architecture definition, and the contract type selected. A common observation was the contract as awarded did not reflect the reality of the system ambiguity. This leads to costly changes and delays (Thomas and Napolitan 1995, Park and Pena-Mora 2003, Song and AbouRizk 2005).

> “The contract was so rigid for this kind of work that it broke.” (Sponsor Project manager)

An extension of this notion of fitting the contract type to the system architecture is one of fitting the contract scope to the contractor’s resources. It is presumed that firms that bid to work on a project have sufficient resources to manage the work should they be awarded it. This of course assumes that the scope reflects the actual work required. It also assumes that the contracting firm is not willing to take on more work than it has resources to handle.[45]

A number of interview subjects acknowledged that a number of firms had either accepted more work than they could handle, or the work had “grown” to the point were they were simply fire-fighting the most pressing issue. As Repenning (2001) points out this mode of operation brings with it significant costs in terms of quality and execution effectiveness.

A final, but often overlooked issue for contract design are the interrelationships that exist amongst the different contracts on a project. Practitioners frequently take the view that optimizing the individual contracts is crucial, but fail to consider the implications of how these contracts interact as a function of the underlying technical system.

Consider the contract “map” shown in Figure 23. This map, taken from an actual project, has one contractor (EP1) on a reimbursable contract for the detailed design and

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[45] Firms may accept more work than their current resource base allows them to handle. They choose to do this with an expectation that they can grow the firm to adjust.

procurement of equipment and materials associated with the topsides and mooring design. Another contractor (H1) is governed by a lump sum contract for the detailed design, procurement of materials and equipment and fabrication of the hull. These two systems, topsides (the hydrocarbon processing and controls equipment) and the hull (the floating support system and hydrocarbons storage package) are highly interdependent.

However, one contractor, under a reimbursable contract has little incentive to limit the amount of redesign they engage in (as each additional hour of work spent optimizing the design is an additional hour of revenue). By contrast, H1 wants to contain changes to the scope so that they can plan the most efficient use of their resources, and hence create a profit from their lump-sum contract. This leads to potential conflict at the boundaries of their respective systems. The project sponsor will undoubtedly have separate teams managing these contractors and they themselves may be in dispute as to how best to resolve any conflicts. This provides a neat example of how contract design, in enacting the system architecture and organizational design, shapes the inter-firm interactions that ultimately deliver shared understanding and trust.

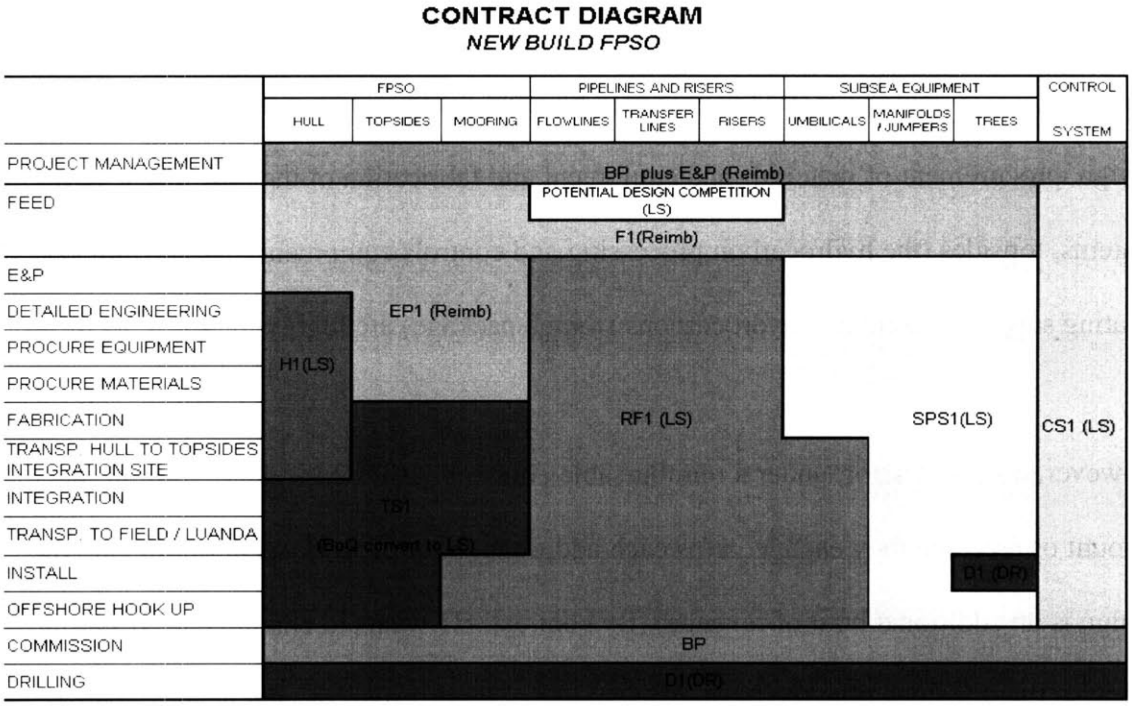

Figure 23: The Contract "Map" for a Major Offshore Development (Source, BP Plc)

5.4.4 *Risk*

Risk in the context of LEPs has a particular meaning to practitioners. The downside consequences of uncertainty (normally considered to be financial consequences but also includes non-financial consequences such as damage to reputation) are typically thought of as "risk", while upside consequences are thought of as opportunities.[46] The appropriate distribution of risk is often seen as a key mechanism for generating alignment (as defined by project practitioners). The following comment is typical:

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[46] The following quote is from a sponsor's guidelines to risk management: "Risks with a positive impact are called opportunities while those with a negative impact are called threats"

> "Our contractors need to have some skin in the game[47]" (Sponsor Facilities Delivery Manager)

Risk is not a single homogenous attribute. Uncertainty exists with respect to multiple dimensions of a project (Lessard and Miller, 2000) and can be organized into different categories (Browning 1998). Risk as a design variable involves the purposeful allocation of control (decision rights) over different categories of risk to specific contractors as a mitigation strategy (Lessard and Miller 2000). Contractors can be expected to focus effort on minimizing their exposure to the potential downside consequences and in so doing are motivated to deliver desirable project outcomes.

Risk involves two aspects; the uncertainty and the consequences of outcomes. Allocation of risk involves both of these aspects. Thus, in making choices for the allocation of risk the following attributes need to be taken into account:

- Who has the appropriate ability (knowledge) to understand and manage the uncertainty?
- Who has the capacity to absorb/bear the downside consequences of potential outcomes?

The answers to the above questions are frequently different and need to be considered independently. Inappropriate assumption of risk by the contractor (or inappropriate allocation of risk to the contractor by the sponsor) may lead to increased commercial risk

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[47] In this case "skin in the game" refers to contractors taking their share of cost increases associated with a project.

for the contractor and defensive work practices by the contractor to mitigate risk which then erodes value from the project as a whole. In this respect, the risk approach of the contract strategy must be consistent with both the sponsor's and the contractor's capacities to control and absorb risk.

An example of the role risk allocation plays in shaping inter-firm interactions is the impact of risk/reward contract mechanisms. These involve contractors assuming a share of any cost overruns on the project, while also being offered a chance to gain on any cost savings. One project that successfully used this approach was the *Norse* North Sea Alliance. In this case the contractors shared a pool of cost savings or losses (calculated against agreed cost targets). Figure 24 shows the payoff function.

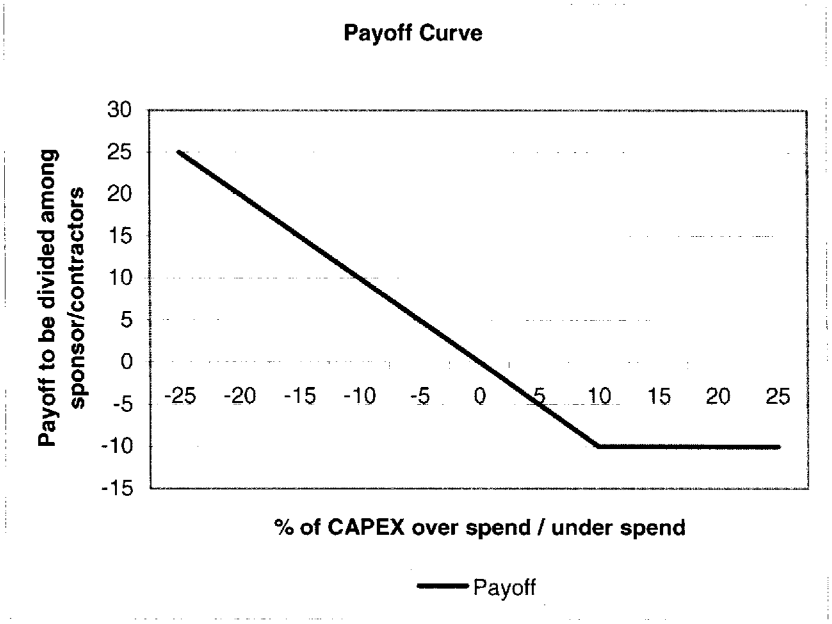

Figure 24: Payoff Curve for the Norse Alliance project.

Note: The loss sharing is capped at -10% of expected CAPEX, while the upside is uncapped. The cost overrun or under run was divided 50% to the sponsor and 50% to the alliance of contractors.

The prospect of shared losses prompted the firms to proactively manage the uncertainties contained in their project scopes, particularly where scopes interrelated. This project demonstrated what Lessard and Miller (2000) describe as a managerial approach to risk management that recognizes that risk depends on the interaction among exogenous risk drivers, managerial choices and the emergence of endogenous factors requiring active mitigation strategies.

5.4.5 Metrics

The oft repeated truism “we make what we measure” is certainly applicable to LEPs. Metrics play an important role in guiding sponsor and contractor teams in their daily activities (Hauser and Clausing 1988, Clark and Wheelwright 1993). The measurement of specific aspects of project, and contractor, performance implies a number of things: (1) that the item being measured is important to the project, either as an outcome of, or an input into, the development process, and; (2) that firms have control over what is measured so that they can intervene to change activities or processes and direct outcomes. The metric factor, as an influence on inter-firm interactions, has the following attributes:

- The extent to which they reflect, or are consistent with, project objectives (for example, a push for standardization of subsystem components)
- The extent to which metrics are integrated across firm boundaries (where outputs from firm A are inputs to firm B, are these measured in a way meaningful for firm B’s process)

Much has been written about the influence of metrics on delivering improved product quality and development outcomes (Hauser and Clausing 1988, Dean and Bowen 1994, Ulrich and Eppinger 2000) and LEPs are similar in many respects. Metrics need to reflect the principal project drivers and the hierarchy of those drivers (Clausing 1988). This includes project performance measures (related to fabrication, operation and maintenance) and organizational metrics (e.g. percent work complete, schedule performance for deliverables).

System performance measures can be improved by employing tools such as Quality Function Deployment (QFD). Organizational performance measures, particularly those that shape inter-firm interactions need to be carefully designed. For example, one contractor, recognizing the danger of measuring project managers on the economic performance of the project separate commercial and system performance measures.

"Project Managers are not evaluated on commercial performance. This limits their motivation to look for solutions that aren't project optimal." (Contractor CEO)

Practitioners frequently expressed concern with respect to how firms' internal measures shape behavior with other firms. It is this aspect of the design of metrics that is particularly important in shaping inter-firm interactions.

5.4.6 Incentives

Sometimes thought of as the primary alignment mechanisms the use of incentives is, as we have seen, only one factor among many that shape inter-firm interactions. Incentives may be financial or otherwise. Incentives in a project environment do not have an unblemished record and the issue of perverse incentives can be evident (Kerr 1975). Indeed many managers offered comments that reflected mixed experiences with incentives:

> "With the wrong incentives, sponsor project managers are driven to deliver commercial performance by driving savings out of contractors" (Sponsor Project General Manager)

Many contractors stated quite simply that the only incentive that really mattered was one linking project performance to repeat business:

> "The main driver of performance is repeat business and the status as a preferred supplier"

The majority of the observations related to incentives struck a cautionary note with concern being expressed about the use of "negative" incentives, such as liquidated damages. These, it was suggested, lead to defensive behavior by contractors; excessive changes and the like. Equally it was noted that when positive incentives are used they had to be derived from genuine project savings and the benefits should be equally distributed among all contractors. Finally, incentive arrangements should be transparent, and where possible provide upside potential to staff as well as senior management; the “flow-down” of rewards was cited as a motivator for genuine team building. The attributes of the incentive factor are:

- Negative vs. positive
- Transparency (of their operation, and their linkages to metrics)
- Reach (where the payoff resides, firm vs. managerial vs. operational level)

5.4.7 Factor Interdependence

Each of the above factors, the “design variables” for inter-firm interactions and ultimately for alignment, makes a unique contribution to the overall pattern of interactions. The six factors also interact with each other in many different ways. Figure 25 illustrates some of the ways in which the six factors influence each other.

	Down Column: How the Factor influences other Factors					
Across Row: What the Factor needs to include into consideration	System Design	Organizational Design	Contract Design	Risk	Metrics	Incentives
System Design		Establishes the capabilities and processes for executing the system design. Manages interfaces, disputes arising from uncertainty. System design, technology, objectives may be selected to account for organizational strengths/weaknesses, processes.	Establishes the entities (firms), capabilities and assets to execute/create the system. Technology and architecture choices may be influenced by availability of skills in market place and contract type used.	Choice of risk profile and ability to allocate risk appropriately may influence technology choice, degree of definition required for system and hierarchy/selection of project drivers and goals.		
Organizational Design	Defines interfaces to be managed/allocated. Defines areas of technology novelty, oversight requirements, drivers/goals to be built into decision making processes.		Determines the oversight, decision authority to be exercised by the Sponsor (e.g. reimbursable contract needs high degree of "hands-on" attention). Choice of program vs. project influences who has decision responsibility and how disputes are resolved.	Choice of risk profile and ability to allocate risk appropriately influences allocation of sponsor staff (e.g. to novel/uncertain scopes/technology choices), design and decision making processes, allocation of decision responsibilities.	Selection of metrics implies control or influence over measured outcomes. Organizational design influenced by what is measured. (e.g. allocation of responsibilities/decision processes consistent with metrics) and the necessary resources to manage and meas	Incentives require administration/oversight, dispute resolution and decision making processes between, and amongst contractor/sponsors.
Contract Design	Defines scope for each contract, establishes the uncertainty associated with each scope.	Capabilities, capacity of Sponsor (skills, No. of staff) required to manage type of contract selected. Establishes dispute resolution, decision making processes for resolving uncertainties, interface challenges. (i.e in choosing Contract types does the or		Risk profile and allocation of risk responsibilities influences choice of contract type, scale and process.	Selection of metrics/KPIs to be included in contract T&Cs. Sponsor metrics may include management of Contractor performance.	Incentive choice may imply certain contract types, scale, processes (e.g. a cost/benefit sharing implies lump sum)
Risk	Establishes overall degree of uncertainty associated with product (technology, system definition) being developed. Determines drivers/targets for product which establishes risk for achieving them (i.e achievable v stretch goals)	Capabilities, capacity of Sponsor (skills, No. of staff) required to manage risk profile selected. Establishes the processes for resolving disputes due to uncertainty of choices.	Contract choice (type, scale, process) determines who holds what type of risk and uncertainty.		Metrics/KPIs influence attention on aspects of uncertainty with the (potential) trade-off of other areas receiving less attention thus changing risk profile.	Incentive selection implies metrics to determine performance around which incentive is based.
Metrics	Establishes goals/drivers and objectives for the project. These should be reflected in metrics.	Allocates staff to manage/measure metrics. Establishes processes for gathering information and interpreting.	Contract choice influences what is important to measure for each contract. Different types of contracts will have different KPIs and respond differently to objectives/goals. (e.g. reimbursable contracts are measured differently to lump sum, and may be mor	Risk profile and specific areas of risk (technology, commercial) establishes areas of focus for measurement.		Incentives influence risk profile (e.g. use of negative incentives stimulates risk averse behaviors in Contractors)
Incentives	Establishes goals/drivers and objectives for the project. These should be reflected in incentives if used.		Contract type, scale and process carry implicit incentives (e.g. Lump sum is an incentive for contractor to reduce costs to increase their margin).	Risk profile and specific areas of risk (technology, commercial) establishes potential areas for use of incentives. (e.g. Contractors may be incentivized to accept higher levels of risk)	Selection of metrics/KPIs influence what is to be used for determination of incentives	

Figure 25: Alignment Factor Dependency Matrix

5.4.8 Capturing Interdependence with Causal Loops

Many of the observations recorded linked multiple concepts, and thus attributes of the six factors, together. Causal loop diagramming is ideal for capturing and understanding these relationships (Sterman 2000). I will describe some of the dependencies amongst the contract design, organizational design and system architecture factors using these tools.

A characteristic of LEPs is that the system architecture (design specifications, performance requirements etc) is difficult to specify completely *a priori.* To enable changes to be accommodated once the contract has been agreed, mechanisms are provided that allows for contractors to make "claims" for additional work; these claims are typically called "change orders" or "variation orders" (VOs). The corollary to this is that where scopes of work are ambiguous exactly what is "in" the scope and what is an "extra" is open to interpretation. Contractors are able to use the scope change mechanisms to generate additional revenue from the project. Obviously, where the scope has been poorly defined, the contractor will have greater opportunity to make claims using these provisions. It is almost received wisdom amongst project sponsors that the contractors use variation orders as a primary source of revenue:

"With no changes they (the contractors) would only make a small profit" (Sponsor Project Manager)

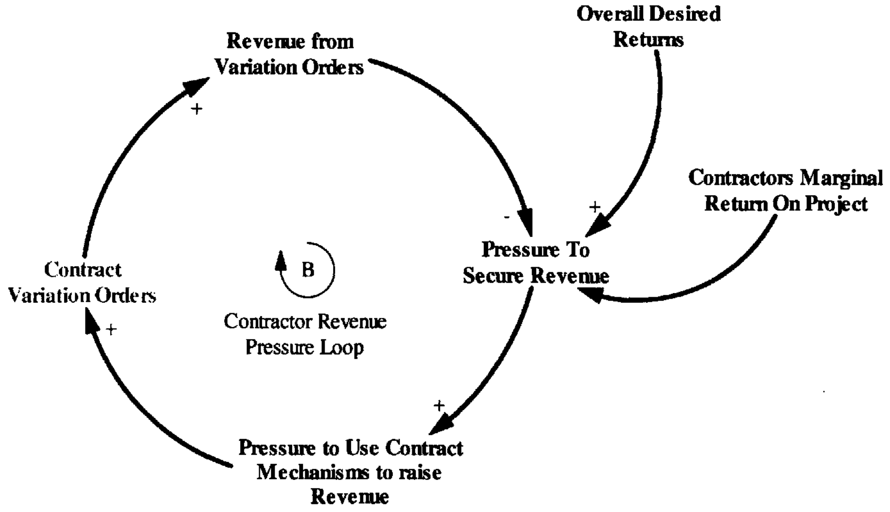

Figure 26: Contract Mechanisms can be Used to Generate Revenue

Figure 26 captures the contractor's use of variation orders to generate revenue on a project. When a gap exists between the desired financial performance for the contractor 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, closing the gap between expected and delivered performance. Poorly defined projects are more susceptible to exploitation of these contractual mechanisms (which link system architecture to contract design).

The selection of key milestones, such as target completion dates (first oil dates), can also have a tremendous impact on aspects of organizational design such as the allocation of resources. Consider the causal loop in Figure 27.

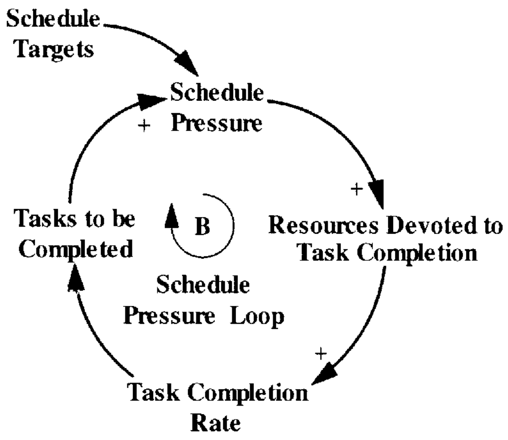

Figure 27: Project Drivers shape Resource Allocation

Choosing “stretch objectives” such as aggressive targets for first oil can lead to “schedule pressure” being applied to the contractors. They respond by devoting more project resources to completing the tasks that fall within their scope of work. They complete these tasks faster and as a consequence the number of remaining tasks is decreased, leading to an easing of the schedule pressure. However, the allocation of resources in response to schedule pressure (in this case) has some additional consequences.

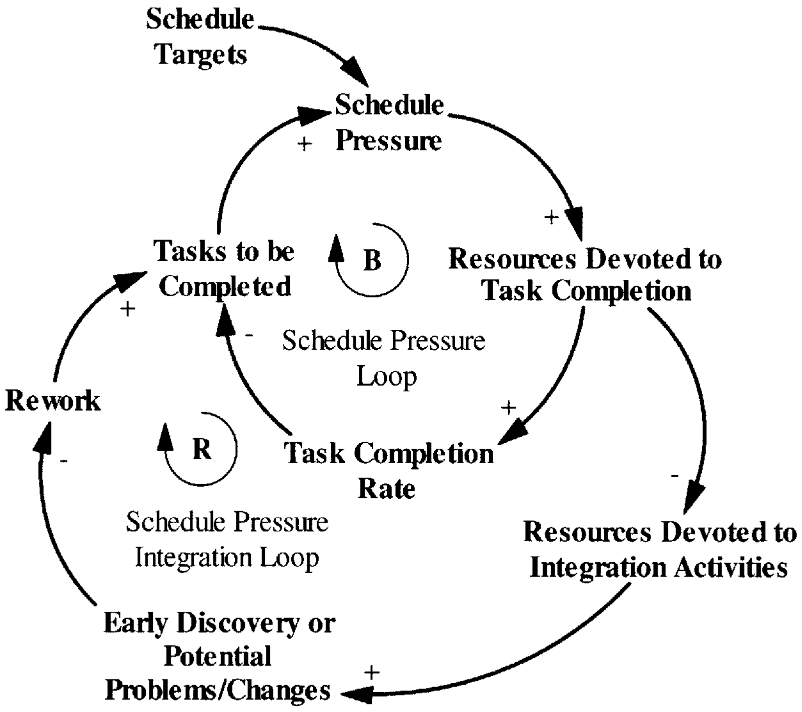

Figure 28: Resource Allocation shapes Error Rates

As resources become focused on completing existing tasks (getting the "piping & instrumentation drawings (P& IDs) out the door") fewer person hours are devoted to integration activities with other contractors or sponsor teams (or even within the single firm). The result of which is a decline in the early discovery of potential design problems. This ultimately creates more rework as problems surface resulting in more work to be done, and an increase in schedule pressure. Here we see an example of how target setting (goals and drivers, an attribute of system architecture) influences organizational design (allocation of resources) and consequently the way in which the firms interact.

Creating more rework results in, *ceteris paribus*, more use of variation orders. And variation orders are not revenue or relationship neutral. As one senior manager from a project sponsor put it:

> "Change orders had a devastating impact; we spent more time on fighting with the contractor and less time on execution (of the project)."

Figure 29 captures this dynamic.

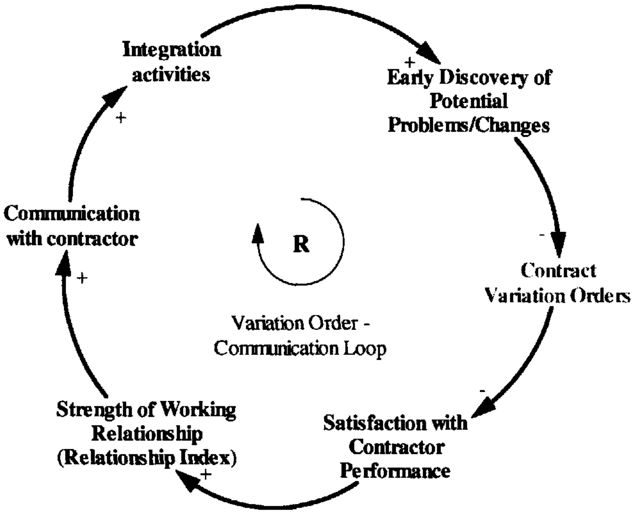

Figure 29: Use of VOs shape Inter-firm Relationships

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* as well as on time. 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 the relationship between the contractor and sponsor is damaged by the VOs firms, and individuals, begin "living down to the contract" and communication suffers (especially in relation to ad-hoc meetings).

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 among 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!

> "The lump sum contract didn't have a well defined scope of work. The contractor hit us with change orders and we spent too much time either arguing about those, or not speaking at all. We spent little time on getting the job done!" (*Glory* Project Manager)

From the above examples we can see that variation orders, a mechanism of the contract design, may serve as a link between the system architecture (the extent to which the scope is well defined) and the organizational design (allocation of resources). This is highlighted in Figure 30:

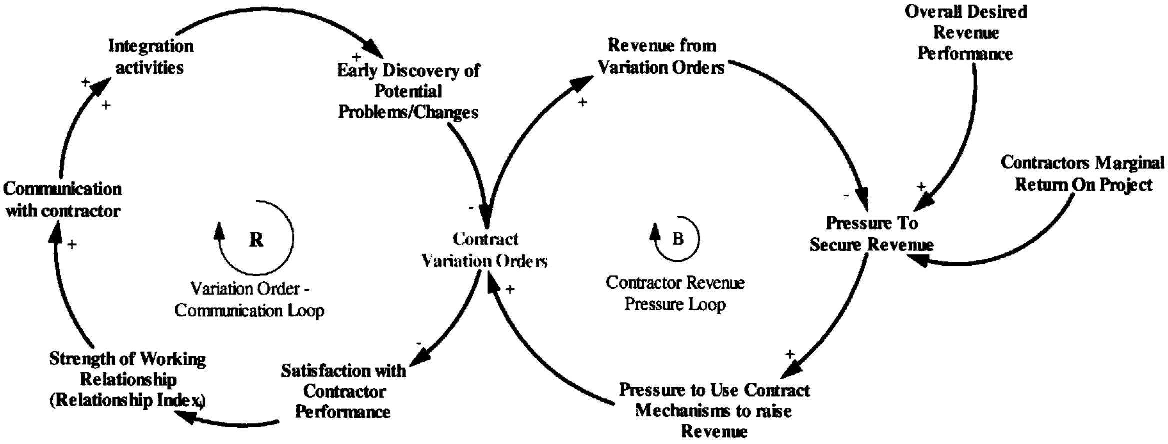

Figure 30: Variation Orders are a Linking Mechanism

A number of other relationships emerge once we begin to link the various causal loops together. Variation orders represent additional work, for both the sponsor and contractor, and as described above can lead to additional schedule pressure. The additional work and consequent pressure may require additional resources. Of course resources are not free, and thus firms may, again, entertain the use of contract mechanisms to pay for the new additional resources. This is shown in Figure 31.

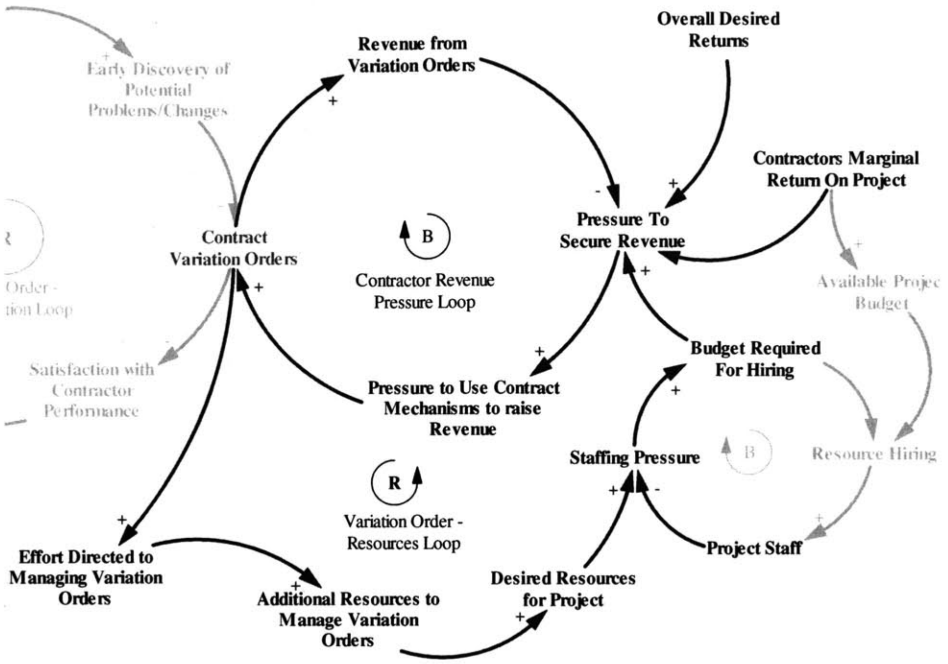

Figure 31: Contract Design shapes Organizational Design

As VOs are generated, effort needs to be directed towards managing them (they need to be documented, audited, tracked, and negotiated over) and this in turn increases the need for additional resources to manage them. This results in an increase in the desired (needed) resources for the project. The project manager feels this in the form of staffing pressure (probably from her commercial group) and the resolution of that (bringing on more staff, and hence more overhead) increases the budgetary pressure on the project's bottom line. One way to relieve that pressure is to use the contract mechanisms available for generating additional revenue; submit more VOs.

As can be seen from the causal loops above, the contract design factor (the form of the contract, agreed price and VO mechanism) interacts with the organizational design factor (number of resources, their allocation to managing VOs or to integration activities) and the system architecture (definition of scope, project drivers and goals). The interactions are captured in Figure 32:

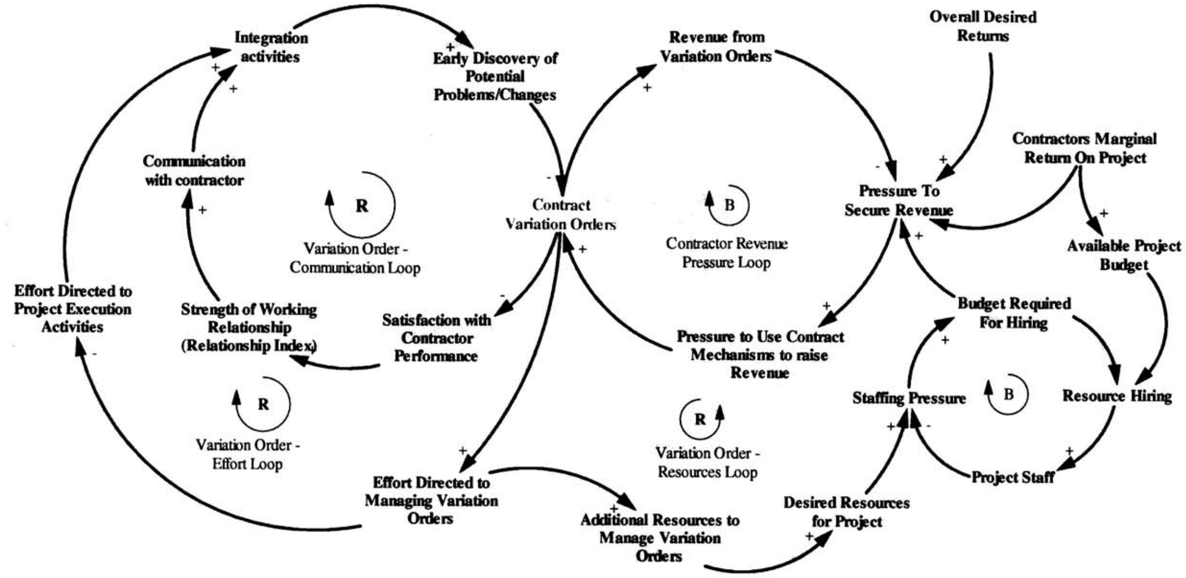

Figure 32: Multiple Feedbacks link the Alignment Factors

The examples, and diagrams above, highlight the complexity of building alignment on LEPs. But we still need to answer the questions posed by our review in Chapters 2 and 3 of the performance of LEPs in general and the *House* project in particular: Why do large projects go so bad when they go bad? And why is it so hard to get them back on track? How do firms get so misaligned? To help answer these questions I employed a formal model that was originally built as part of my Masters research (McKenna 2005) and subsequently modified for my doctoral work.

5.5 A Dynamic Simulation Model

The causal loops described above were incorporated into a formal dynamic project model and simulated using system dynamics (Sterman 2000). The model was based on well established project models using the rework cycle as a fundamental element (Abdel-Hamid and Madnick 1991, Repenning 2001, Ford and Sterman 1998, 2002). It extended these models by distinguishing between the project sponsor and the contractor who executes the project. Previous system dynamics models had assumed that the project took place "under one roof", i.e. the project was directed and executed by one firm (a full description of the model is available in the Appendix). The model was simulated under a range of exogenously established "agreed contract rates" (the hourly rate for engineers agreed between the project sponsor and contractor) which endogenously determined the lump-sum price between sponsor and contractor. The model then simulated the effects of varying the agreed rate, while leaving the contractor's "preferred rate" and "break even rate" fixed. The model captured the causal structures shown above and added the following interaction mechanisms amongst the alignment factors:

1. Agreed contract rates (contract design) influence the contractor's decisions to allocate (hire) resources at the start of the project and the extent to which they hire staff during the project (organizational design).
2. The strength of the relationship (determined by key performance indicators) influences the contractor's willingness to use VOs (contract design) and the allocation

of resources to integration activities (organizational design): adversarial (poor) relationships increase the contractor's willingness to use VOs and reduces their investment of resources in integration activities.

A number of interesting results appeared from the analysis. The first was that projects which appeared to be "cheaper", that is they began with low initial prices, ended up being significantly more expensive than planned.

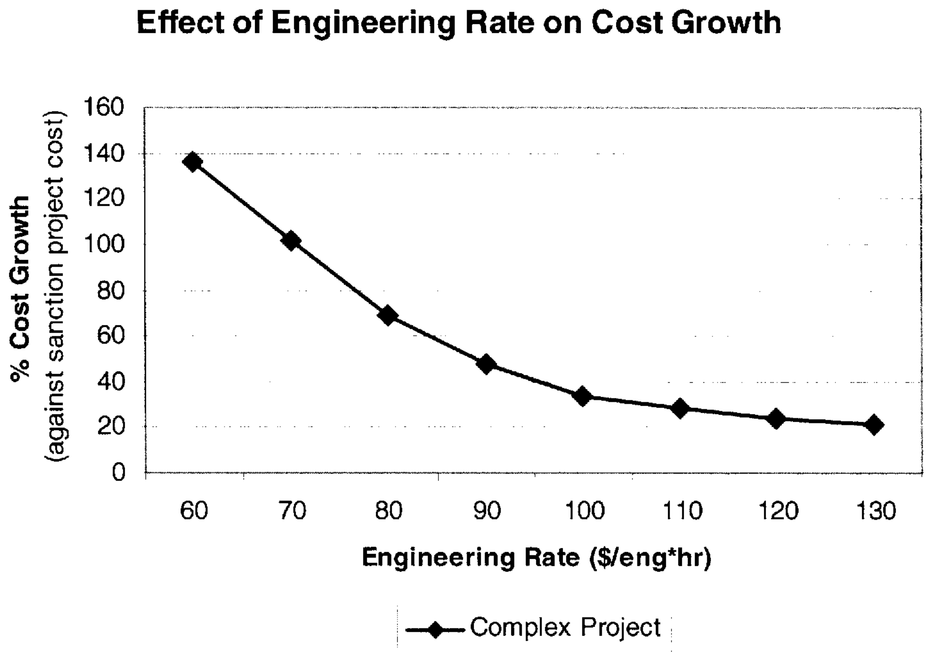

Figure 33: Project Cost Growth

Figure 33 shows the increase in final project costs over expected costs (the agreed "sanctioned" lump sum cost) for a range of agreed engineering rates (and thus lump-sum prices in the model). For all rates the simulated project experienced some cost growth[48], but as can be seen above the "cheaper" projects were significantly worse than those projects operating closer to the contractor's preferred rate of return (the contractor's preferred rate is $100/eng*hr, with a break even rate of $70/eng*hr). "Cheap" projects led to final costs well over double the expected costs (an expectation based on an heroic assumption of "cheaper up front cost = money saved"). It should be noted that the final project costs shown above do not include the "costs" associated with the delays the project experiences. Delays lead to loss of revenues for the project sponsor, and for operating oil fields, such delays can quickly generate losses that exceed the capital costs of the projects.

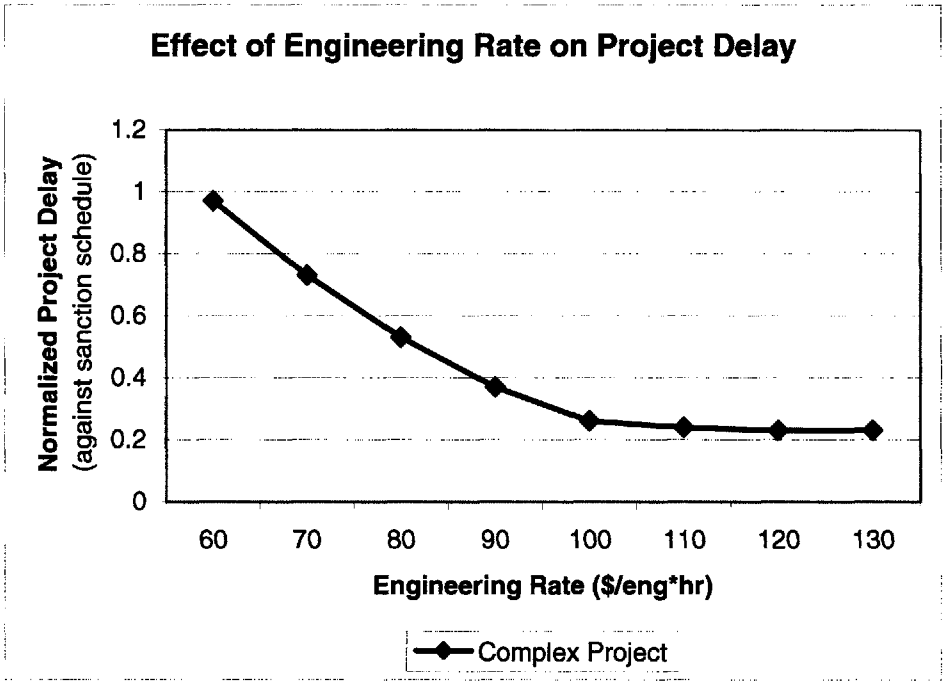

Figure 34: Normalized Delays (against original schedule)

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[48] This can be explained by the fact that the simulated model, like all projects, included ambiguity leading to errors and thus rework. This cannot be avoided altogether, even for projects with contractors making good returns. Thus all simulated projects experience some rework leading to delays, variation orders and cost increases. The point of interest is not in relation to the absolute increase experienced by all simulated projects, but by the relative outcomes generated by alternative pricing strategies.

In Figure 34 the delay experienced by the simulated projects has been normalized against the initial target completion date. Again, all project experienced some delay (see footnote 48 above), however the point of interest is the much larger delays experienced by projects operating with contractors under financial duress. Against a target of 200 weeks the "cheapest" project is eventually completed in week 393.

The outcome for the simulated project proved to be sensitive to how much time was ideally required for integration activities. A variable in the model, *Ideal Integration Time Fraction*, established the amount of time the contractor should spend on integration activities in order to minimize error generation and rework. This variable can be thought of as a proxy for the complexity of the project's system architecture; complex projects require a much higher fraction of the available time spent on integration activities than simple, well defined, modular systems. The plot below shows the difference in cost growth, for a range of engineering rates, between a "complex" project (the base case for the runs above – i.e. a project with a higher *Ideal Fraction Time Spent on Integration*) and a "standard" simpler project. Both projects had the same number of tasks to perform and the same schedule.

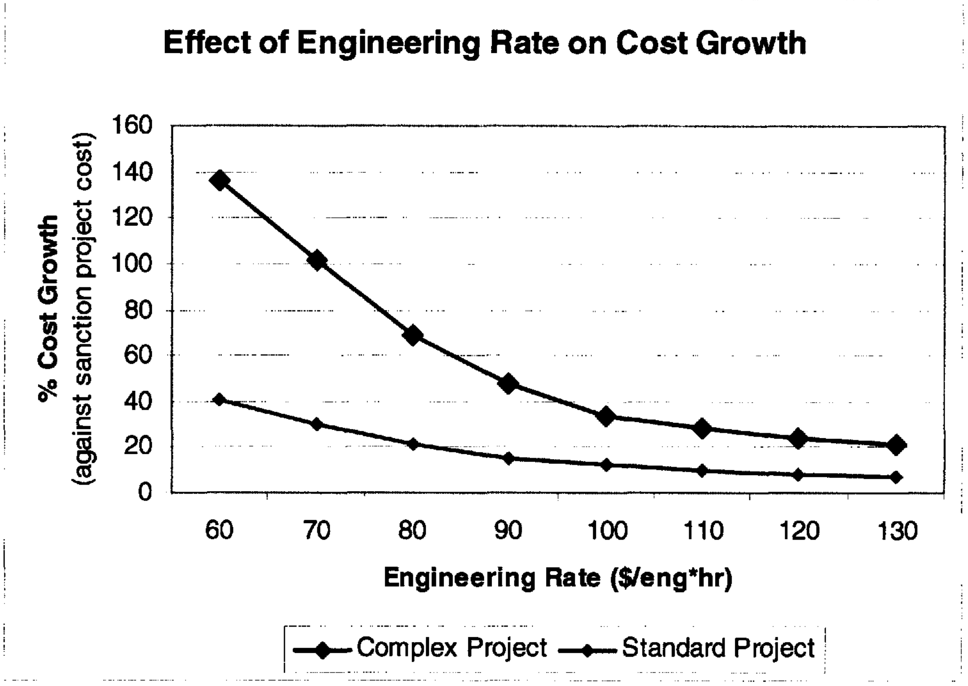

Figure 35: Performance of Complex vs. Standard projects

Figure 35 might be interpreted to suggest that in all cases the sponsor is best off paying the contractor more because this leads to a lower percentage cost growth. However, if we look at the absolute cost outcomes, rather than percentage increase a different story emerges.

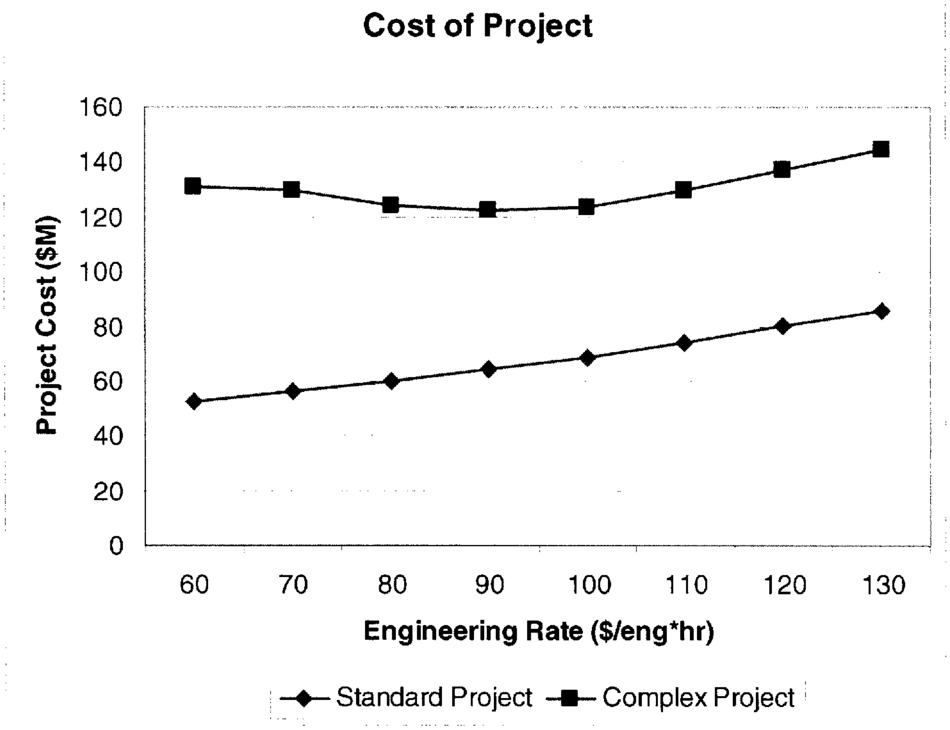

Figure 36: Absolute Values of Project Costs – Standard vs. Complex projects

Figure 36 compares two projects, the complex base case (with *Ideal Fraction Time Spent on Integration* = 0.4, i.e. engineers working on the project should ideally spend 40% of their time verifying the interfaces of their work with that of other subsystems – a proxy for project complexity) and a simple "standard" project (*Ideal Fraction Time Spent on Integration* = 0.1). Each has the same number of tasks to perform and the same schedule. The simpler project however, while experiencing the cost growth shown in Figure 35, rewards the sponsor for driving down the contractor's rate. Costs increase over the bid price, but not enough to offset the gains from hard bargaining. The more complex project begins with higher initial lump sum costs[49] but also displays quite different behavior. The "cheaper" projects end up costing close to the most expensive options, while also finishing much later. In this case the sponsor pays a significant penalty for taking a zero-sum approach to price negotiations.

Figure 37 shows *percent project cost growth* for a range of projects from simple systems (complexity = 0.1) to very complex systems (complexity = 0.5). The simpler systems show a muted response to the effects generated by low contract rates. This makes intuitive sense; systems that feature less complexity are less sensitive to variation in effort devoted to integration activities.

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[49] The model endogenously calculates the lump sum price; the model "contractor" incorporates the time and cost for dealing with the more complex project and hence a higher starting point for the price results. The complex project has on average a 50% greater lump sum price than the simpler project at equivalent rates.

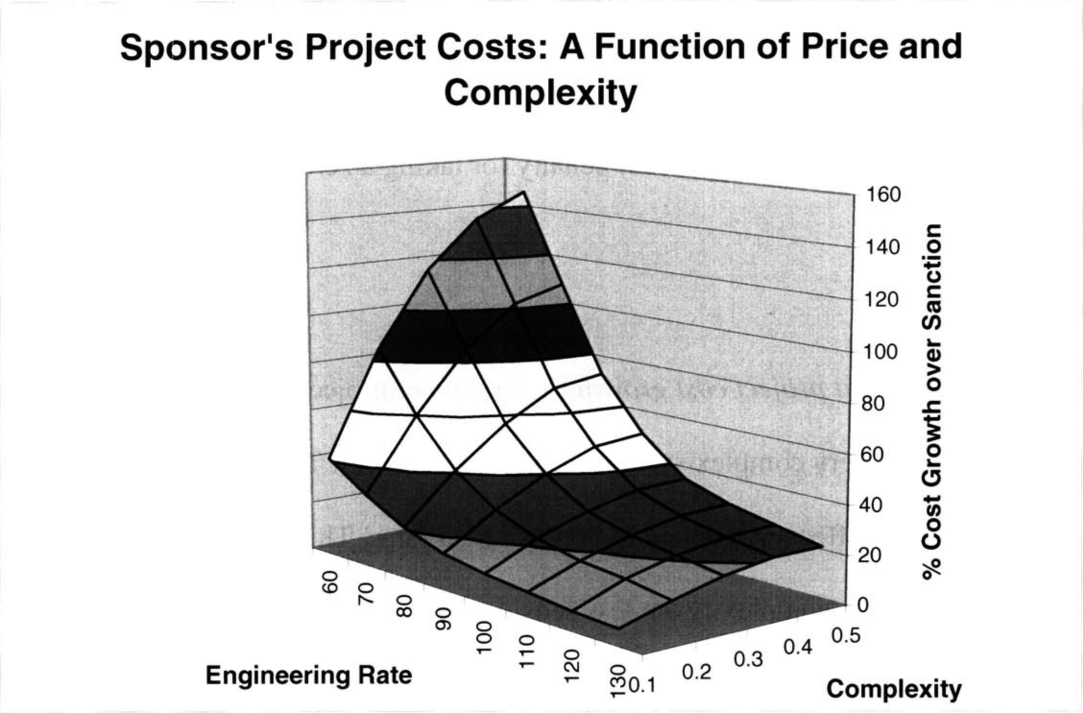

Figure 37: Complex Projects are Sensitive to Contract Pricing Effects

The model was also simulated (using the base case project across the range of agreed engineering rates) with the sponsor introducing a 20% increase in project scope half way through the original schedule without adjusting the schedule accordingly (i.e. simply adding more work while demanding the same completion date). The plot below shows the percentage change in the project delay from the delay experienced without the scope increase. It can be seen that the more expensive projects fared worse, in comparative terms, than the "cheaper" projects.

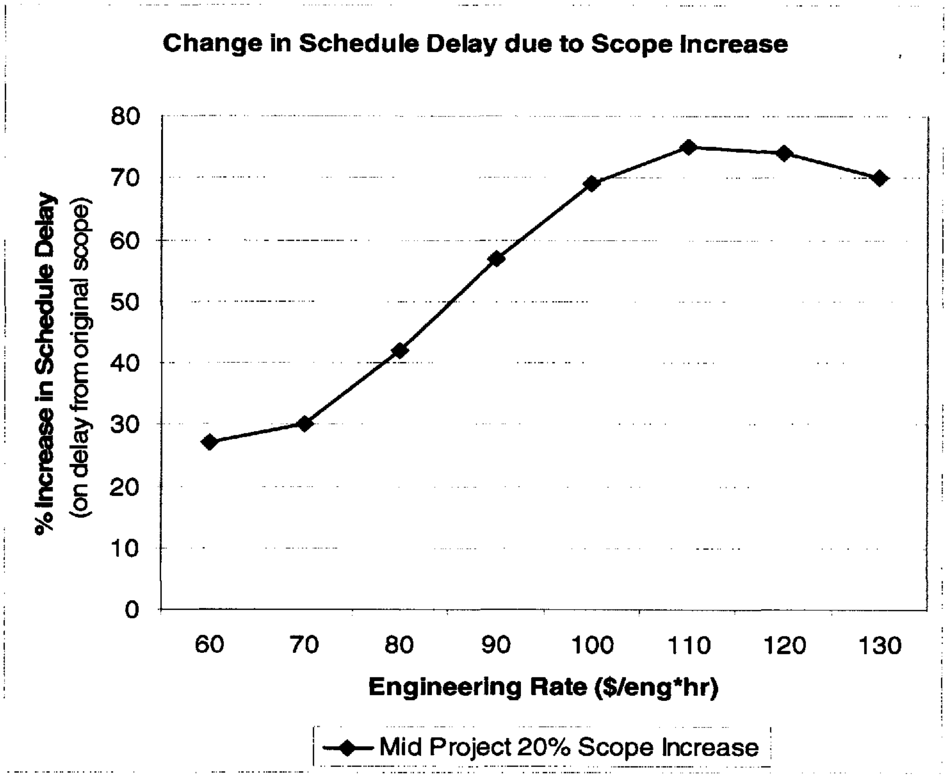

Figure 38. Schedule Delay Caused by Scope Increase as a Percentage of the Base Case Delay

Why do the projects with higher rates, generally, fare worse in responding to the late changes?

One answer is offered by considering what happens to the relationship between the sponsor and contractor when the change is instigated. In simple terms, the “cheap” projects with relationships already tending towards adversarial are damaged incrementally less than the expensive projects. However, projects near the preferred rate, or just under, are most sensitive to the change of scope and can see relationships quickly collapse. Figure 39 shows the *Relationship Index* (RI) variable from the model. Three rates are simulated, $130/eng*hr,

$90/eng*hr and $70/eng*hr. The top two lines show simulations for the top rate with and without scope change (change occurs at week 100). The RI declines once the scope change is announced but steadies after a while. The bottom two lines are for the $70 rate with and without scope change. Here the additional scope causes the RI to continue its downward trend at a slightly greater rate. The middle two lines are for the $90 rate – making a profit but below the preferred rate for the contractor. The scope change at week 100 instigates a steady decline in the RI which is also a larger net change in RI than either of those experienced by the top, or the lower rate projects.

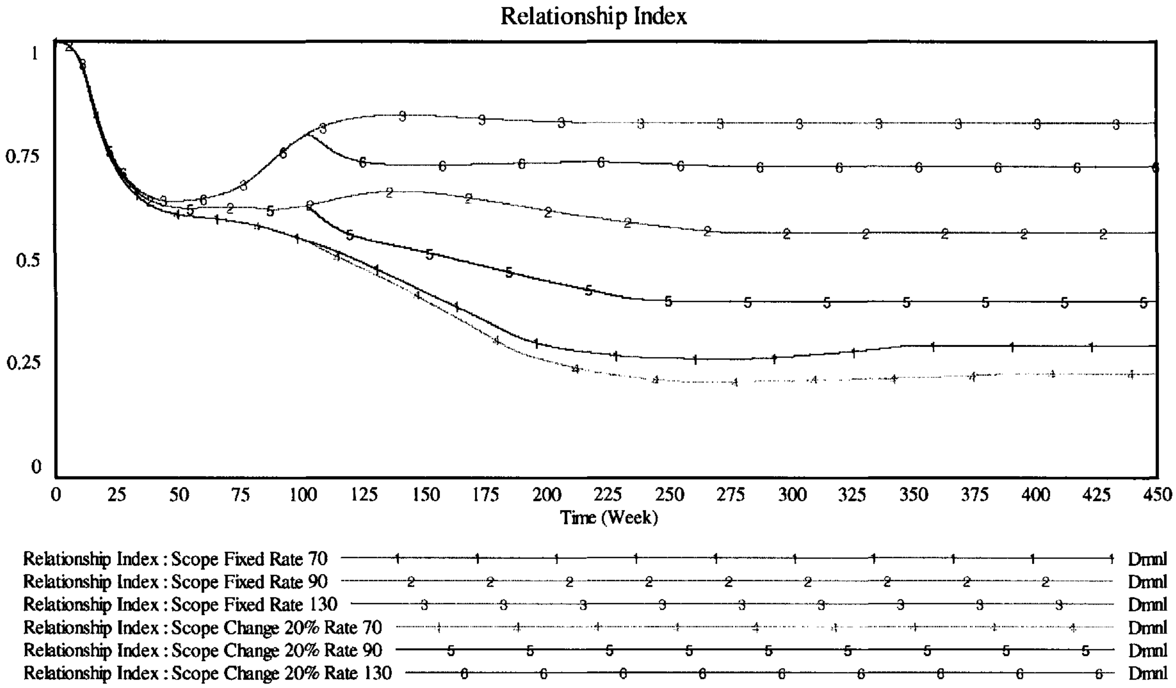

Figure 39: The Impact of Scope Change on Inter-firm Relationships

Analysis of the formal model offers us several initial insights. Firstly, the various alignment factors interact, sometimes strongly, and in often counter-intuitive ways. Secondly, "cheaper" projects may end up costing more than notionally more expensive ones. Furthermore, complex projects appear to be more sensitive to the interaction effects of the six factors.

A deeper insight is that the low engineering rates served in the model as a catalyst for the generation of a negative reinforcing dynamic structure; an adversarial relationship of limited interaction and increased use of formal contract devices. They help tip a project into behavior dominated by the collapse of the relational aspects of the inter-firm interactions. The extent to which this occurs was modified by the complexity of the project and the profit margin desired by the contractor.

In the real world, in contrast to the simulated one, the point at which the collapse of the relationship begins to dominate the project is not self evident (we may be unaware of the financial condition of firms engaged on the project, or just how coupled the subsystems and scopes of work are). The main insight to be gained from the model is that sponsors and contractors need to build robust mechanisms, in addition to those contractually specified, that maintain a strong relationship; once it collapses the ability to overcome the reinforcing dynamics that result is limited.

This chapter identified shared understanding and inter-firm trust as being the antecedents of alignment. They are primarily generated through interactions among firms, and practitioners, (Weick 1993, McAllister 1995, Dyer 1997, Zaheer et al 1998, Kramer 1999, Weick et al 2005) and so I sought to identify the factors that shape those interactions. The six alignment factors, the design variables if you will, were then presented along with examples of their complex interactions and a formal model of these interactions. The next chapters draw upon existing literature to frame the complex interactions among the six factors that shape inter-firm interactions. The ultimate aim is to develop a framework for practitioners that will assist them in making the institutional and personal investments needed to develop the appropriate inter-firm interactions. As Williamson (1993) stated "Economic activity will be better organized where there is an appreciation for and intentional use of informal organization."

6.0 Understanding Inter-firm Interactions

As we saw in Chapter 5 the problem of alignment is very messy. Firms search for shared understanding of the project and for trust with each other. Achieving this involves at least the six factors identified and their interactions. The six factors are:

- System architecture
- Organizational design
- Contract type
- Risk
- Metrics
- Incentives

We may be able to understand how these factors interact in shaping the emergence of trust and understanding by considering them "through the lens" of existing theories that address inter and intra organizational interactions.

In the following sections I will employ two established approaches to understanding organizations. The first of these is the study of high reliability organizations by, amongst others, Perrow (1983, 1986) LaPorte and Consolini (1991), Weick (1993), Weick and Roberts (1993) and Carroll, Rudolph and Hatakenaka (2002). The second explicitly considers the role of contracts in determining the actions of agents and principals. I will draw upon the work of Macauley (1963), Baker, Gibbons and Murphy (1994, 2002), Gibbons (2005, 2006), and Klein (2002).

6.1 High Reliability Organizations

High reliability organizations (HROs) share many fundamental characteristics with large engineering projects (described in detail below). Moreover, HROs operate and exist in a socio-technical environment with the engineered systems that LEPs design and construct: nuclear power plants, nuclear powered aircraft carriers, civil aviation infrastructure, and offshore oil and gas production facilities.

6.1.1 Characteristics of HROs

Perrow's work on "normal accidents" identified the characteristics of risky systems. They feature (1) interactive complexity: multiple-use components, proximity of components, common mode connections, unintended feedback loops; and (2) tight coupling: limited time to devise remedies, other equipment or supplies or personnel can not be substituted and alternative ways of running the system, or shutting it down, cannot be utilized (Perrow, 1986). He identified examples of risky systems (nuclear power plants, aircraft systems, nuclear weapon systems, chemical plants) and subsequently they became the setting for a number of organizational studies.

LaPorte and Consolini (1991) investigated aircraft carrier flight operations and FAA air traffic control operations as each organization "operates tightly coupled, complex, and highly interdependent technologies. Each also faces very dynamic physical, economic, and political environments."[50] Carroll et al (2002) noted that high-hazard organizations are "distinctive work settings that include potential harm or death to large numbers of individuals in a single event, such as an explosion or crash."[51]

LaPorte and Consolini (1991) suggested that HROs differ from "failure tolerant organizations" (i.e. most organizations) in three critical respects:

1) The physical technologies and operating units are tightly coupled. If a component fails the capacity of the organization to function is severely threatened.
2) The results of operational failures are visible and feared by the public. The public perceive that they have a high stake in assuring failure-free operations and strong external public pressure exists for reliable internal operations (not only for overall performance or economic profit).
3) They have relatively abundant resources allowing investment in reliability enhancing activities.

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[50] LaPorte T, T., Consolini P, M, 1991, pp 21

[51] Carroll J, S., Rudolph J, W., Hatakenaka S., 2002, pp 92.

The traits of risky systems and the organizations that operate them are clearly present in large engineering projects. First, consider the fundamental trait of tightly coupled organizational and technical systems. Williams (2005) neatly describes the nature of large complex projects as being evident along two dimensions:

- Structural complexity made up of the size, or number of elements in the project, and the interdependence between these elements, where "elements" are organizational as well as technical.
- Uncertainty, made up of uncertainty in project goals, and uncertainty in the means to achieve these goals.

Miller and Lessard (2000) describe LEPs as "unique, dedicated, and usually one-off products with intensive interactions between sponsors and contractors"[52] and then list examples: airports, urban-transport systems, oil fields and power systems. Each of these systems feature complex and coupled technologies which, during the project phase, are being developed and built by multiple firms sharing intensive interactions. Furthermore, as we saw in Chapters 2 and 5, projects feature dynamic non-linear feedback processes (Sterman 2000) echoing Perrow.

The second trait of HROs is that of highly visible and publicly feared failure. Failure for LEPs can take different forms: (1) the traditional project failure of cost overruns and delays,

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[52] Miller R, Lessard D, R., 2000, pp 7.

or (2) a spectacular system failure leading to property damage and potential loss of life. Both failure modes are highly visible and feared by the public. Consider the first failure mode.

Chapter 2 highlighted the poor economic record of LEPs. For example, an average cost overrun of 46% on 14 oil and gas mega-projects resulting in increased capital expenditure of $11.8 Billion (Merrow 2003), or the 90% of major transport infrastructure projects that were overspent (Williams 2005). Economic failure of this magnitude can be significantly damaging, particularly to the project stakeholders and communities they are meant to serve. But what of the second type of failure? Are LEPs also risky systems that contain the threat of physical harm to property, the environment and individuals? I will offer just a small set of examples from the oil and gas industry as evidence of the high risk nature of LEPs.

Bea (2000) details a number of cases where human and organizational errors[53] led to failures of offshore structures. One case study, involving an unidentified MODU (mobile offshore drilling unit), detailed the sinking of the vessel with the loss of all onboard. The author (Bea) was involved with the accident investigation and the conclusion was that while failure of a critical supporting structure that occurred during operation had its "root cause embedded in a design error"[54], the error was allowed to occur because of failures throughout the design organization. Bea cited a "lack of critical situation awareness"[55] within the design organization as contributing to the ultimate failure of the system.

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[53] Bea R, G., 2000, pg 163
[54] Bea R, G., 2000, pg 165
[55] Bea R, G., 2000, pg 165

The sinking of the concrete gravity base platform Sleipner A in a Norwegian fjord in 1991 is another example of an LEP exhibiting the failure characteristics of an HRO. In this case, fortunately, no one was killed. The construction crew managed to abandon the partly built floating facility before it sank in the 200m deep fjord. The impact of the hull (which weighed in excess of 1 million tons) on the seafloor caused a seismic event which registered 3.0 on the Richter scale. The failure involved an economic loss of $700 million and a delay of two years[56]. Again, while detailed design error was the proximate cause of failure, the ultimate cause was described as organizational; "because of time and budget limitations, detailed overview and checking had been curtailed"[57].

LEPs feature the tight coupling and interactive complexity of high-hazard systems. The failure of LEPs, either in terms of high impact sudden failures leading to loss of life and property damage, or the massive erosion of value due to delays and cost overruns are certainly visible and feared by the public (just think of the public expense of projects such as Boston's $14.6 billion Central Artery/Tunnel Project, known by Boston locals as the Big Dig!) Perhaps the main differences between HROs and LEPs are that firstly LEPs exist for a defined duration whereas HROs are typically on-going, and secondly LEPs do not tend to have abundant resources. They may require enormous amounts of capital, but their resources usually get stretched once the project runs into the (almost) inevitable delays. Indeed the lack of resources has been a cause of spectacular LEP failures as we saw in the Sleipner A case.

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[56] Selby R, G., Vecchio F, J., Collins M, P., 1997.

[57] Bea R, G., 2000, pp 166

With the similarities established, what can the organizations that successfully manage high-hazard technologies teach the organizations that design, engineer and construct these same systems?

6.1.2 Heedful Interrelating and the Collective Mind

As pointed out by several researchers (LaPorte and Consolini, 1991, Weick and Roberts, 1993, Grabowski and Roberts, 1999 and Carroll, Rudolph and Hatakenaka, 2002) high reliability organizations have been successful in delivering organizational goals of performance and safety. They have been able to do this through a variety of organizational mechanisms that enable diverse groups to act in a coordinated manner despite high degrees of environmental uncertainty. We can use our understanding of these mechanisms as a prism through which to view the six factors and their role in building shared understanding and inter-firm trust and ultimately alignment.

Weick and Robert (1993) described the formation of a "collective mind" within the crew of a nuclear powered aircraft carrier. "Mind" for Weick and Roberts was conceptualized as "actions that construct mental processes" by which they meant that individual actions were the means by which a higher-order pattern of interrelated activities emerged[58]. Weick and Roberts focused, in particular, on the connections that linked distributed activities, for example, the act of landing an aircraft:

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[58] Weick K, E., Roberts K, H., 1993, pp 374

> "Recovery (of an aircraft) is a set of interrelated activities among air traffic controllers, landing signal officers, the control tower, navigators, deck hands, the helmsman driving the ship etc" (Weick and Roberts, 1993, pg 363)

Actions were taken with "heed" when they displayed a disposition to act with attentiveness, alertness and care. They contrasted heedful actions with heedless interrelating which was characterized by actions that are the result of attention being focused narrowly rather than on the joint situation, (Weick and Roberts, pg 371). Choosing to act in a heedful manner was assisted by the building of shared meanings through language, stories and rules; a "socially constructed field" which was the referent for individual actions.

Building the social field was not trivial and involved a rich set of activities; processes for interrelating included rules such as a pilot not moving an aircraft until signaled by the appropriate person from the appropriate spot and socialized behaviors such as experienced personnel trading "war stories" with newcomers (Weick and Roberts 1993). Through these processes a collective mind was enacted which encouraged heedful interrelating amongst individuals.

This is analogous to the firms engaged on an LEP searching for shared understanding. Relating this idea back to the notion of alignment, we can see that aligned firms, those that have successfully created a socially constructed field, should be expected to act in "heedful" ways. We can now begin to examine the six factors as ways in which the project sponsor and contractors go about building the collective mind.

6.1.3 Mechanisms for Interaction

LaPorte and Consolini (1991), Weick and Roberts (1993), Weick (1993) and Carroll, Rudolph and Hatakenaka (2002) all detail numerous processes that individuals or teams engage in to maintain the performance of their particular HRO. LaPorte and Consolini (1991) report that "HROs use a proactive, preventative decision making strategy. They build decision making patterns."[59] Carroll et al (2002), in reference to the Millstone nuclear power plant and the development of a safety culture, stated that:

> "Openness and trust emerged organically through multiple mechanisms and venues that encouraged participation, diversity of viewpoints, and attention to solving and averting problems."[60]

These mechanisms fall into two broad categories; formal and informal processes. The formal processes are those that are based on hierarchy, standard operating procedures and enforceable rules. The informal processes are those that occur as a result of emerging circumstance, or through social processes (war stories).

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[59] LaPorte T, R., Consolini P, M., 1991, pp 29.

[60] Carroll J, S., Rudolph J, W., Hatakenaka S., 2002, pp 116.

The formal mechanisms are typically established to deal with routine, complex and understood tasks (LaPorte and Consolini 1991, Galbraith 1974). Operational predictability drives HROs to establish stable processes (LaPorte and Consolini 1991) codified and enacted through standard operating procedures (SOPs). However, as Carroll et al (2002) point out, these standardized procedures can limit the ability of the organization to learn (i.e. operating in the constrained stage of organizational learning), and to react appropriately when the environment is less certain. Nonetheless, these SOPs build the standardized patterns of interaction that enable familiarity and trust to develop amongst interdependent teams (Weick and Roberts 1993, LaPorte and Consolini 1991).

However these formal mechanisms, while necessary, are not sufficient to deliver the heedful interrelating required for satisfactory performance in high uncertainty environments. Additional informal adaptive practices are required. During periods of peak demand (increased uncertainty, emergent challenges or heightened numbers of tasks) bureaucratic processes are replaced with informal non-hierarchical practices (LaPorte and Consolini 1991, Weick and Roberts 1993, Carroll et al 2002). These are typically based upon the technical and tacit knowledge of individuals regardless of formal authority (acting, according to La Porte and Consolini, as a "bureaucratic solvent"). Examples given include the role of the Chief in aircraft carrier operations guiding upwards and downwards, and the fluid transfer of authority amongst FAA controllers during peak traffic periods. Driving this shift to informal adaptive processes is the failure of bureaucratic mechanisms to adapt fast enough to changing circumstances.

Despite sharing completely aligned goals, namely the safety of the plant and with it their own and most likely their family's safety, the various groups within the Millstone nuclear power plant required more than agreed goals to create a safety conscious work environment. "Millstone had to find its own way to move from a regime of centralized authority and mutual distrust to a culture of open communication, trust, and participation."[61] Carroll et al (2002) highlighted the role shared knowledge played in achieving this. Carroll et al (2002) extended the role of knowledge from a "bureaucratic solvent" to a boundary object (Carlile 2002) enabling teams to build trust and understanding.

The study of the Millstone nuclear plant revealed the use of shared knowledge and analytic approaches to build bridges across disciplines and "equalize status". Activities formed in this context served as boundary spanning mechanisms that allowed diverse views to be heard, dominant mental models to be challenged and common problems to be addressed (Carroll et al 2002). Shared understanding among the different groups within Millstone was the foundation for building trust amongst previously disputatious organizational teams.

Weick et al (2005) describe an environment where the reverse was true; respect for, and trust of, another lead to the creation of shared understanding. In this case, the operation of a medical facility for the care of premature babies, a senior nurse was able to direct the attention of the attending physician towards the needs of a patient in a way that junior staff

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[61] Carroll J, S., Rudolph J, W., Hatakenaka S., 2002, pp 117.

could not. It was not a case of the junior staff having less knowledge per se (indeed it was a junior nurse who had first diagnosed a potential problem with a patient), rather it was the trust the physician had for the senior nurse that motivated the doctor to make an effort to examine the child and to call for surgeons to attend: "(the attending physician) knew she (the senior nurse) knew what she was doing"[62].

6.1.4 Using the Six Factors to Construct a Shared Cognitive Field

The events described at Millstone, and elsewhere, suggest that having agreed goals is necessary but not sufficient to deliver alignment. HROs are able to deliver reliable performance through the creation of "collective mind" founded on shared knowledge and trust – a socially constructed field (Weick 1993, Weick and Roberts 1993). Alignment among firms on LEPs is analogous. And in a similar manner to the HROs, multiple mechanisms are required to achieve the required end state, formal and informal.

The definition and division of scope, establishment of *a priori* metrics and key performance indicators, and the allocation of authority through formal contracts are analogous to the standard operating procedures. They provide known routine mechanisms through which the firms interrelate. And, like the formal mechanisms of HROs, are most useful when tasks are either routine or well understood. Formal mechanisms, such as the *a priori* definition of scope, also serve as boundary spanning objects. Project teams use their shared understanding

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[62] Weick K, E., Sutcliffe K, M., Obstfeld D., 2005, pp 413.

of the scope as a boundary object to explore and create new knowledge about the project needs.

Critically, as argued elsewhere, are the emergent integration activities. These serve as the "bureaucratic solvent" that allow firms to discover shared solutions and build heedful ways of interrelating (across hierarchies and amongst contractors). The shortcoming of formal mechanisms can be somewhat overcome through these processes. An indicator of practitioners' understanding of this process is the aphorism stated by (almost) all interview subjects:

> "The best contract is the one that gets left on the shelf"

However, formal mechanisms can equally serve to promote heedless interrelating. Firms can be encouraged by the terms of the formal agreements (such as distribution of risks, incentives or metrics) to take a narrowly focused view of the project. The informal mechanisms, such as ad-hoc integration meetings, allow projects to contend with novel, unique and highly uncertain frontiers between firms. Again, this is analogous to the HROs adapting or improvising (Weick 1993) in the face of peak demands.

The desired outcome of the mix of processes is the establishment of trust and shared understanding amongst individuals and the distinct firms. As Carroll et al (2002) state; "Trust emerged through collective action and perception of shared interest", and it was this built environment of trust that allowed the Millstone nuclear plant to satisfy the regulators that it had successfully created a “safety conscious work environment”. Through the lens of the investigations into HROs it is becoming possible to discern how the two antecedents of alignment; (1) shared understanding of the project and; (2) trust based inter-firm interactions, act in concert to deliver alignment. Each reinforces the other. A lack of one impedes the other. Together they provide the basis for building a self-enforcing alignment mechanism. It therefore becomes the goal of LEPs to use the six factors in such a way as to build inter-firm trust and promote knowledge sharing.

6.2 The Economics of Contracts

Understanding the mechanisms that enable HROs to maintain high performance in highly uncertain environments provides insight into how the six factors can shape performance within LEPs. However the theories of organizational behavior that emerge from the study of HROs fail to addresses a central and critical fact about LEPs. Project organizations are formed from a group of legally distinct and autonomous firms by the use of formal contracts. The high reliability organizations studied were typically integral and unitary. We need therefore to add to our analysis by employing an alternative framework. Economic theories of exchange between a principal and an agent provide us with some traction in this discussion. Agency theory, and its assumptions of utility maximization, limited observability of actions, and the ever-present chance of opportunism, provides an appropriate framework to investigate the actions of profit maximizing firms and approaches aimed at generating alignment among them.[63]

6.2.1 *Incentive Theory*

The basic formulation of the classic incentive contract (the cornerstone of agency theory) is as follows (Gibbons 2005):

1. The principal and agent agree a compensation contract that pays wage (ω) for an output (y). i.e. $\omega(y)$.
2. The agent chooses an action (a), but the principal cannot observe this action.
3. The action (and environmental effects, often called a "noise" term ε), determine the agent's output (y).
4. The agent receives the compensation specified by the contract (ω).

The principal's utility (U) is $y-\omega$, the agent's utility is $\omega-c(a)$, where c(a) is the cost to the agent of taking the action (a). This basic formulation has been modified and extended over time to incorporate the effects of incentives on the agent: $\omega = s + b(y)$, the wage now includes a salary (s) and a bonus (b) which is a function of the output (y). Recognition has

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[63] I do not intend to review all (or even a small fraction) of the work in economics devoted to contractual exchange. That endeavor is well beyond of the scope of this meager paper. Instead I direct readers to Brousseau E., Glanchant J., 2002 for a very broad overview. For detailed review of formal agency theory I recommend Gibbons, 2005. For a more critical perspective of the offering of economics in relation to organizational theory I invite the reader to peruse chapter 7 from Perrow 1986.

been granted to the fact that the output itself may not be easily measured and so performance measures are employed as proxies; as is the case in the real world (Holmstrom and Milgrom 1991). The technology of production delivers output $y = f_1a_1 + f_2a_2$, the technology of measurement provides the performance metric $p = g_1a_1 + g_2a_2$ (there are also multiple actions that can be taken rather than just one). Compensation is now $\omega = s + b(p)$. In this context the essence of the incentive problem becomes clear. As Gibbons (2005) states, it is "the divergence between the agent's incentive to increase p and the principal's desire to increase y." In this formulation alignment between the principal and agent is achieved by having the vectors of functions f_n and g_n coincident.

The inclusion of the effects of separating output from measurement attempts to capture the ideas expressed in Kerr (1975). However, these models still fail to capture the rich variety of organizational decision making that takes place in the real world. Few decisions made within firms are strictly based on formal contracts (Perrow 1986, Baker, Gibbons and Murphy 2002). This is in part because, outside of strictly theoretical realms, all contracts are incomplete (Klein 2002, Williamson 2002). Macauley (1963) detailed numerous instances of firms using ad-hoc negotiations, or drawing upon personal relationships (trust), to resolve unexpected problems which were unspecified in the formal contract; "these customs can fill in the express agreements of the parties". Macauley also noted with some surprise (being a law professor) that some firms adopted dispute resolution procedures in an ad-hoc manner without reference to the formal contract, even if it contained relevant provisions! He concluded that firms seldom use legal sanction to adjust relationships, and when it occurs it is the result of a calculative decision where the gains were thought to outweigh the costs.[64]

Baker et al (2002) formally develop the ideas expressed in Macauley (1963) and argue that exchange between a principal and agent takes place within the framework of both formal and relational contracts. A formal contract is specified *ex ante* in terms that can be verified *ex post* by a third party (traditionally thought of as the courts). A relational (informal) contract is sustained by the expectation of future payoff based on outcomes that can only be observed by the contracting parties ex post (and thus cannot by specified beforehand nor verified by a third party).

Baker et al (2002), Gibbons (2006), model the interaction of the formal and informal contracts as a repeated game where the agent and principal play trigger strategies.[65] These formal techniques have been applied to a number of organizational questions; including the theory of the firm (Baker et al 2002), and the role of hierarchy within a firm (Baker et al 1999). The lessons for LEPs from these investigations are manifold: (1) that effective formal contracts may increase the use of informal contracts (Baker et al 1993); (2) the combination of formal and relational contracts can reduce distortion in the agent's incentives and reduce the principals' temptation to renege on a promised bonus; (3) where non-contractible rights of control are too numerous and complex to be controlled by an individual the exercise of

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[64] Macauley S., 1963, pp 55

[65] Essentially the two parties begin the relationship by cooperating, and then continue to cooperate until one side reneges, at which point they refuse to cooperate anymore. The outcome post reneging has different outcomes in different models; in some cases reneging leads to no more actions being taken by the agent and thus the end of production, in others the two parties resort to just the formal contract.

these rights must be coordinated by relational contracts (Baker et al 2002), and; (4) the formal and informal aspects not only co-exist but also interact, creating an opportunity to choose the former to facilitate the latter (Baker et al 2002).

6.2.2 The six factors: formal and relational contracts

The dual nature of contracts (formal and relational) within the environment of LEPs is evidenced by a turn of phrase used by more than one manager:

> "The last thing we want is contractors living down to the contract"

It reveals not only that there are interactions that take place between firms that are not specified (i.e. relational), but that these informal structures enable work to progress smoothly. Living down to the contract is a threat. Because contracts are incomplete, sticking to only the explicitly specified tasks within a contract usually brings much of the meaningful work to a halt.

> "If we had followed the contract to the letter we would be here for another year."
> (Contractor Project Manager)

The six factors that emerged from the research include attributes that could be classified as either formal or relational. For example, the actual formal contracts along with the *a priori* definitions of scope, allocation of risk, explicit metrics and incentives fall into the former category. The ad-hoc integration and design meetings, subjective performance metrics (for example, measuring contractors by their "effort" in collaboration with the sponsor teams) and building co-located and integrated project teams, all fall into the latter category. Notionally the relational contracts help maintain project performance, and the formal contract plays a role in supporting the relational:

> "The fully cost reimbursable project needs an incentive to keep up (the contractor's) spirit." (Contractor Project Manager)

This quote highlights the use of formal mechanisms (an incentive scheme attached to the reimbursable contract) to maintain the relational aspects of the exchange (the contractor's spirit). Of course the formal model in Chapter 5 showed that the interaction between formal and informal mechanisms is definitely a two edged sword.

Classical incentive theory suggests that sponsors need to select the appropriate performance measure (p) along with incentive function (g) such that the contractor's effort to achieve the bonus b(p) delivers the desired output y. Unfortunately for LEPs, the desired output y is impossible to specify with any certainty, the actions to be taken by the contractors are uncertain (even to them), and the selection of the appropriate performance measures is an extremely complex task. It is therefore of paramount importance that the sponsors, recognizing the likely shortcomings of any formal contracts, devote resources and attention to developing robust relational contracts (again as the formal model demonstrated).

The mix of formal and relational contracts operates at multiple levels within a project: within teams, across contractors, between sponsor and contractor. The relational contracts are particularly critical amongst contractors as, typically, no formal contracts link individual contractors together other than indirectly through the sponsor. The six factors provide levers that managers can use to build the relational contracts that are crucial in generating the self-enforcing alignment mechanism. As stated by Baker et al (2002):

> "Our model highlights a role for managers: the development and maintenance of relational contracts both within and between firms."

6.3 Marrying Economic and HRO perspectives of Alignment

Gibbons (2006), drawing upon the decade of work by Baker, Gibbons and Murphy (1993, 1999, 2002) informs us that the themes of their work with agency theory are three-fold; (1) formal and relational contracts interact; (2) relational contracts assist parties to remedy imperfections in formal governance structures and; (3) the formal structure should be chosen for how it effects the formation of relational contracts in addition to its own impacts. The themes transfer directly to our understanding of how firms interact when working on LEPs and furthermore are supported by the results from the formal simulation model. In addition, the attributes of the six factors can be classified by the extent to which they display the characteristics of formal or relational contracts. For example, within a formal contract (specified *ex ante* and verifiable *ex post* by a third part) metrics can be nominated as part of the contract between a sponsor and a contractor and performance relative to those metrics can be verified by the courts. Thus we can approach the attributes of the six factors with a view to implementing the advice of Baker et al (2002); develop and maintain the relational contracts.

The cognitive perspective developed in the high reliability literature offers a number of insights. Firstly, creating the "heedful interrelating" that enables high hazard organizations to function requires a mix of formal mechanisms (standard operating procedures for example) and informal mechanisms (transfer of authority based on tacit knowledge). This qualitative finding neatly echoes the conclusions reached more formally in economics. Furthermore, the mix of formal and informal mechanisms generates a socially constructed field characterized by shared knowledge and trust. It is the existence of both trust and shared understanding that enables organizations to navigate the potential disasters of high hazard operations.

A clear pattern emerges when the insights gained from the HRO literature and those from economics literature are taken together. Complex systems involving decision making and knowledge building under uncertainty require a mix of formal and informal (relational) mechanisms to build shared understanding along with interpersonal and inter-organizational trust. The formal and informal mechanisms interact and while both a necessary, neither is sufficient independent of the other. Alignment (heedful interrelating) requires both trust and shared understanding. This realization provides guidance for the theory of alignment and also contributes a framework for its implementation in practice.

7.0 A Theory of Alignment

The previous chapter considered the six factors of alignment in terms of two existing theories of intra and inter firm behavior. These theories implicitly (High Reliability Organizations) or explicitly (Contract Economic) highlighted a distinction between formal and informal mechanisms of control within and between organizations and each concluded that optimal outcomes required the appropriate use of both mechanisms. The high reliability literature further proposed that organizations maintain performance in an environment of uncertainty by building trust and shared understanding. The theory of alignment amongst firms delivering large engineering projects is consistent with this conclusion.

Daft and Weick (1984) employ the arguments of Thorngate (1976) to contend that a theory of social behavior, which my theory of alignment certainly is, cannot be simultaneously general, accurate and simple. I have followed their lead in proposing a model of inter-firm alignment that is "general and simple, but is not very accurate at specifying details"[66].

7.1 A Theory of Alignment

The synthesis of insights provided by the literature on high reliability organizations, economic models of contractual relationships and formal modeling of grounded research

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[66] Daft R, L., Weick K, E., 1984, pp 294.

generated a theory of alignment amongst firms delivering large engineering projects. The theory proposed is a middle range theory (Merton 1968) which is founded on the empirical observations of a distinct organizational system.

7.1.1 A Self-enforcing Alignment Mechanism

The generation of alignment requires the development of two antecedents amongst the project firms: (1) a shared understanding of the task at hand (broadly defined), and (2); a general expectation of other firms' reliable, predictable and fair behavior. The first of the two required alignment antecedents involves building an environment that shapes decision making towards mutually acceptable outcomes. This requires a rich and detailed shared understanding of the project enterprise and its intent (including constraints, objectives, firm motivations and aims, task requirements etc), complete with decision heuristics to support the selection of particular solutions from amongst alternatives in ambiguous settings, which can be described as a *shared cognitive field* (March and Simon 1958, Simon 1959, Simon 1979, Weick 1993, Weick and Roberts 1993, Weick et al 2005).

Table 5: The Attributes of the Shared Cognitive Field

Shared Cognitive Field
• Understanding project objectives and constraints • Understanding project tasks and boundaries • Understanding project uncertainty and coupling • Decision making and heuristics

The second antecedent of alignment is the development of an environment in which firms believe (and act on this belief) that other firms can be relied upon to meet their obligations, behave predictably and act with good-will towards others. Such an environment can be described as exhibiting *inter-firm trust* (Williamson 1993, McAllister 1995, Zaheer et al 1998, Javenpaa and Leidner 1999, Kramer 1999, Carson et al 2003).

Table 6: Attributes of Inter-firm Trust

Inter-firm Trust
• Confidence of the others competence and reliability • Consistency of behavior • "Fair" behavior with respect to opportunism • Reciprocity

The two antecedents of alignment interact to build a self-enforcing alignment mechanism. This is shown in Figure 40.

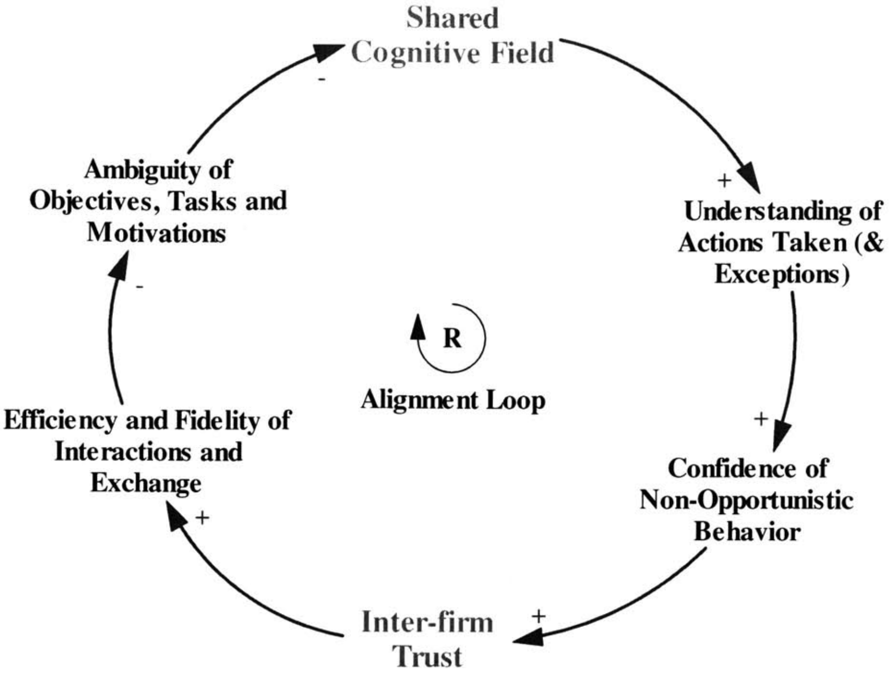

Figure 40: Self Enforcing Alignment

Consider the reinforcing causal structure shown above. A shared cognitive field facilitates understanding with respect to decisions made and actions taken (March and Simon 1958, Simon 1959, Carson et al 2003). Importantly, and as argued by Carson et al (2003), shared understanding allows firms to distinguish between a genuine mistake (or outcome resulting from uncontrollable influences) and opportunism when firms fail to meet expectations (i.e. exceptions to expected behavior). This enables confidence in predictable, reliable behavior with respect to the non-opportunism of another to be maintained and to accumulate; a critical outcome given the fragile nature of trust between firms (Zaheer et al 1998, Kramer 1999). The development of inter-firm trust follows (Williamson 1993, McAllister 1995, Mayer et al

1995). It has been shown (Zaheer et al 1998, Dyer 1997) that inter-firm trust improves the efficiency of transactions. This trust also mitigates the fear of opportunism between firms (Kramer 1998, Carson et al 2003) which supports the efficient and detailed exchange of information facilitating knowledge building (Nonaka 1994, Dyer and Nobeoka 2000). The efficient exchange of rich information then assists firms in building a shared cognitive field (March and Simon 1958, Huber 1990, Weick 1993, Carlile 2002, Weick et al 2005). With the journey around the causal loop complete we can see that the self-enforcing alignment mechanism is constructed by the existence of *both* a shared cognitive field and inter-firm trust.

7.1.2 Alignment as a Reinforcing Structure

The causal structure of alignment is described as self-enforcing because it is reinforcing. Greater shared knowledge leads to better understanding of actions taken and increased confidence of non-opportunistic behavior (when the actions are revealed to be non-opportunistic). This increases trust, in turn improving the efficiency and fidelity of information exchange, reducing the remaining ambiguity surrounding tasks, motivations and constraints, which in turn increases the stock of shared knowledge.

However, reinforcing structures can act with equal vigor in detrimental ways. A lack of trust for example impedes the open exchange of information increasing or maintaining the uncertainty and ambiguity surrounding motivations, tasks and constraints. The development of a shared cognitive field is impeded reducing understanding of the actions taken (and what actions to take) with the consequence of declining confidence of others fair, reliable and non-opportunistic behavior. This further impedes the development of trust.

The self-enforcing mechanism generates alignment, or mis-alignment, among the firms of an LEP. It is tempting to hypothesize that it is the existence of this reinforcing structure at the heart of the inter-firm dynamics of LEPs that may be, in part, responsible for their peculiar bimodal performance. When self-enforcing alignment is operating in a beneficial way projects display effective performance, but when it operates in a detrimental manner the result is a project "wreck".

7.2 Framing the Theory

Perrow (1986) suggested that an organizational theory has three critical components that need to be explicated. These three components are: (1) assumptions; (2) propositions and; (3) operationalizations. Huber (1990) referencing Blalock (1969) defines a theory as "a set of related propositions that specify relationships among variables" before going on to stress that "more is expected from a theory, such as a framework that integrates the propositions" (Huber 1990, pg 64). In the following sections I set out my limiting and working assumptions, offer the principal propositions of the theory of alignment and propose a general framework for the operationalization of the theory.

7.2.1 Assumptions:

The theory of alignment is constrained to a particular set of circumstances by four limiting assumptions. I enumerate these below:

1. The theory is essentially one of inter-firm relationships. However, where intra-firm mechanisms explicitly influence inter-firm behavior these are considered and included. Examples of internal factors that are relevant because of their external implications are internal performance and reward metrics, internal stakeholders (e.g. procurement vs. operations) and firm drivers.
2. The context is the design and delivery of complex products. These products feature significant uncertainties, emergent properties, are typically integral systems and are likely to be characterized by a high degree of interdependence with tight coupling amongst system elements.
3. The work (activities and tasks) associated with the delivery of the product is knowledge driven. The members of the organizations that carry out these activities are knowledge workers such as skilled/craft laborers or engineers, managers and members of the professional classes.
4. Firms considered for this research and resultant theory are profit seekers (if not always maximizers). My theory excludes government agencies, regulatory bodies and non-government organizations.

To echo Daft and Weick (1984) the theory of alignment is, like any organizational theory, built on a set of specific assumptions about the nature of organizations. Three specific assumptions underlie my theory.

1. Trust, understanding and ultimately alignment are experienced by individuals working within firms. These are phenomena that shape individuals choices and actions. Micro-level actions though can lead to macro-level effects (March and Simon 1958, Weick 1993).
2. Notwithstanding the agent specific nature of trust, understanding and alignment, individuals can, and do, form feelings of trust towards institutions such as firms (Zaheer at al 1998, Carson et al 2003). Firms can also preserve knowledge, attitudes and behavior in ways that are then accessed by individuals (Nonaka 1994, Carroll et al 2002)
3. Interactions among firms can be classified as either formal or informal. Formal interactions are those framed by either contract (terms specified ex-anti that can be verified ex-post by a third party) or hierarchical (bureaucratic authority based rules and procedures) means. Informal interactions are non-contractible behaviors that are established, or emerge, ex-post contract award in support of project execution (Baker, Gibbons, Murphy 2002, Gibbons 2006, Perrow 1986).

The above assumptions taken together establish the limits of my theory, and the foundations upon which it is built.

7.2.2 Propositions:

My theory of alignment can be stated in the form of two linked propositions:

1. Alignment is generated by the existence of:
    a. A shared cognitive field consisting of understood project objectives, constraints, task requirements and boundaries, identified uncertainties and interdependencies with supporting decision heuristics, and;
    b. Inter-firm trust, consisting of firms having confidence in their expectations of the dutiful, competent and fair behavior of others.
2. The shared cognitive field and inter-firm trust are built through:
    a. Informal inter-firm interaction mechanisms that provide a means for firms to deal with imperfect formal inter-firm mechanisms, and;
    b. Formal inter-firm interaction mechanisms that enhance the development and use of the informal mechanisms.

The propositions above establish a theoretical framework for building alignment on large engineering projects.

7.2.3 Operationalizations:

The propositions outlined above are operationalized via the six factors identified earlier: system architecture, organizational design, contract design, risk, metrics and incentives. The six factors are listed below along with their attributes.

Table 7: Attributes of the Six Alignment Factors

System Architecture	Organizational Design	Contract Design
Drivers/Constraints Performance Specification Form Specification	Coordination and Communication Allocation of Resources Allocation of Authority (Decision Rights)	Contract Form Contract Scale Contract Award Process
Risk	**Metrics**	**Incentives**
Knowledge of Uncertainty Capacity to Bear Downside	Consistency with project drivers Integration across firms	Negative vs. Positive Transparency Reach

Project management professionals, trying to build alignment among the firms engaged on a LEP, have no managerial "lever" labeled "trust" or "shared understanding" that they can pull. Nor do they have "formal interaction mechanism" and "informal interaction mechanism" levers to employ. Rather they have the six factors identified and their attributes. In the following sections I will outline some broad principles for operationalizing alignment using these six factors, along with illustrative examples.

7.3 The Six Factors and Inter-firm Interactions

The theory proposes that alignment is generated by the existence of a shared cognitive field and inter-firm trust. These act together to form the self-enforcing alignment mechanism.

Building shared knowledge and trust requires the use of informal interaction mechanisms to manage imperfect formal mechanisms. And, the careful design of formal interaction mechanisms to enhance the development of informal mechanisms. Below I will offer some examples of each (the formal and informal interaction mechanisms) as they relate to the six factors. In each section below I will list examples of mechanisms and indicate in brackets which of the six factors the example relates to. The diagram below captures the relationships described.

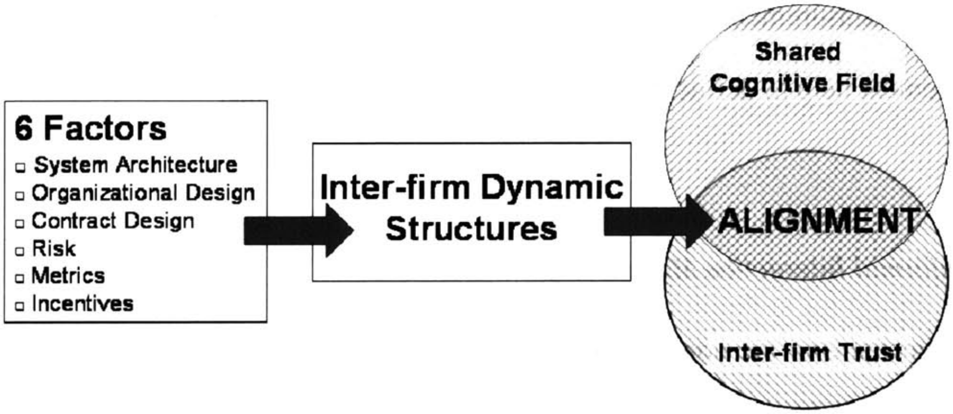

Figure 41: The Architecture of Alignment

7.3.1 Formal Interaction Mechanisms

Formal mechanisms can exist within or between firms. The formal contracts between firms establish one category of mechanisms. The explicit contract terms include, *inter alia* the contract scope (system architecture), key performance indicators (metrics), a set of objectives (system architecture), defined communication media or design software (organizational design), project milestones (metrics) frequently linked to payment terms (incentives) and liquidated damages for late delivery of scope (risk).

Formal hierarchical and bureaucratic controls within a firm define the second type of formal mechanism and include standard operating procedures (organizational design) and existing internal authority and hierarchy requirements for decision making (organizational design), e.g. authority to approve purchases is often strictly controlled and only certain grades of senior project managers have sufficient authority to approve large capital expenditure. In addition, factors such as explicit firm goals and drivers (system architecture) and internal performance measurement and reward systems (metrics and incentives) that exist at project commencement help to define the formal interaction mechanisms.

7.3.2 Informal Interaction Mechanisms

Informal mechanisms are non-contractible behaviors i.e. they cannot be specified before hand in such a way that they could be enforced by a third party (the courts). Rather they emerge once the project commences with the aim of enabling project execution. An example of an informal interaction mechanism is the establishment of ad-hoc design review and integration meetings among project professionals, both within firms and across firm boundaries (organizational design). These meetings emerge as the project moves forward. Teams seek information from other parts of the project enterprise in order to progress their design, or they seek to impart information so as to verify that their design is compatible with others. The frequency of such meetings and the personnel attending them cannot, practically, be specified in advance.

The output of such meetings often results in revisions to the design of the system or revision of the expected performance envelope (system architecture). Thus the system architecture acts both as a boundary object (Carlile 2002) and evolves over time. In so doing the system architecture factor acts as both a formal mechanism and an informal mechanism.

Other examples of informal interaction mechanisms include having consistent and transparent contract pre-qualification procedures (contract design), consistently communicating (organizational design) the hierarchy of project drivers (system architecture), establishing a "no blame" policy for less than desired performance (metrics), having an integrated project team with limited evident hierarchy between sponsor and contractors (such as "badged" office doors, or all sponsor staff on a separate floor of the building) or the choice of the number of sponsor staff needed for oversight of contractors (organizational design).

7.3.3 Classifying the Six Factor Attributes

The descriptions above provide illustrations of how the six factors provide the instantiations of the theoretical formal and informal interaction mechanisms. The factors are in essence the design variables to be used by project practitioners in their efforts to build alignment. Table 8 lists the six factors and categorizes their attributes as either applicable for use in constructing formal or informal interaction mechanisms. In some cases an attribute may in fact be able to act as both a formal and informal mechanism.

Table 8: The Six Factors listed by Formal and Informal Attributes

Alignment Factor	Formal Mechanisms	Informal Mechanisms
System Architecture	• Performance & Form Spec in Contract • Drivers in Contract	• Emergent Specifications
Organizational Design	• Communication (specified media) • Hierarchy of Authority • Resources (Contractual allocation of)	• Communication (ad-hoc meetings, reviews etc) • Decision process (Collaborative vs. Authoritarian) • "Badge" of staff
Contract Design	• Contract Form • Contract Scale • Award Process	• Award Process • Contract Scale (success based guaranteed work)
Risk	• Capacity to bear liability • *A priori* Knowledge	• Emergent knowledge of uncertainty
Metrics	• Key Performance Indicators (KPIs) • *A priori* Internal Metrics	• Integrated KPIs across firms
Incentives	• Pay-off functions • Negative vs. Positive	

7.4 Implementing Proposition Two

Proposition two of the theory of alignment states that a shared cognitive field and inter-firm trust are built through the use of informal interaction mechanisms to deal with imperfect formal mechanisms and the careful design of formal mechanisms to enhance the use of informal mechanisms. The six factors are the design variables through which project practitioners create the inter-firm interaction mechanisms. Section 7.3 above illustrated the formal and informal classification of the six factor attributes. The next section provides illustrative examples of how project practitioners can employ the six factors to enact proposition two from the theory of alignment.

7.4.1 Informal Mechanisms Deal with Imperfect Formal Mechanisms

Formal contracts are incomplete, and are likely to be so in a number of ways. Firstly, they are ambiguous with respect to defining the specific tasks at hand and the knowledge required to execute them, and secondly in establishing the grounds for making optimal decisions even if knowledge was certain and available. In addition, for complex projects developing tightly coupled systems, it is unlikely that any single project team (or firm) will have sufficient knowledge of all aspects of the project that affects their work. Thus, while formal mechanisms may allocate authority to the approximate location of "best" knowledge[67] it is the informal mechanisms, (ad-hoc design reviews, communication amongst engineers etc), that enables the best knowledge to be created such that appropriate decisions are made.

The classic example of informal interaction mechanisms helping to deal with imperfect formal mechanisms is the use of collocation of teams (organizational design) to promote communication (organizational design). The positive effects of collocation on team performance, particularly in product development settings, is well established (Allen 1977, Keller 1986, McDonough et al 2001). A further example, drawn from my interviews, was the

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[67] This assumes that the contract is consistent with Jensen and Meckling's (1990) view that decision authority should be passed to those with the appropriate knowledge. In this way, formal contracts construct hierarchical authority across firm boundaries in respect to certain tasks (Stinchombe 1990).

promotion of a “no blame” policy for instances of performance failing to meet desired levels. In this instance, when contractors brought up potential or real problems for the project, the sponsor took an approach of “we’re all one team so how can I assist in developing a remedy” rather than the “well, that’s your problem. Why did it happen?” (Contractor Project Manager). The policy promoted early discussion of possible problems, frequently leading to early solutions avoiding costly late changes.

7.4.2 Formal Mechanisms can Enhance Informal Mechanism Development

As became evident from the results of the formal model simulation, informal interaction mechanisms, such as ad-hoc integration meetings, can be encouraged or discouraged by the formal interaction mechanisms employed. Consider the following examples. Setting an aggressive schedule (system architecture) and linking it to contract penalties (such as liquidated damages), can inhibit a firm’s willingness to commit time and resources to integration activities. Project managers are likely to ensure that “their” work is done as a priority and informal activities suffer as a result (as does, potentially, the whole project). A further example is provided by the interaction between the key performance indicators (KPIs) and other metrics as part of the formal mechanisms (either within the contract or within the sponsors firm), and the development of informal mechanisms. A contractor tasked with designing the topsides, for example, may be measured by the percent complete of the P&IDs (piping and instrumentation drawings). The location of piping runs has multiple interfaces with the hull design. However the metric of percent complete P&IDs motivates the topsides contractor to move forward rapidly with delivering AFC (approved for construction) drawings. The hull designer meanwhile may want changes to the location of the topsides piping to optimize hull stiffness, strength or constructability. But, with topsides P&IDs being a key performance metric the topsides contractor is unwilling to accommodate changes (to the system architecture) and is unlikely to engage fully with the joint problem solving activities such as ad-hoc design review and "clash checking" meetings required (organizational design). The sponsor may be forced to intervene to direct one of both firms to accommodate changes. Depending on the contract types (contract design) governing the sponsor relationships with the contractors, an intervention may invoke change order claims (contract design) against the sponsor and damage the establishment of a collaborative project environment (the instantiation of informal inter-firm interactions).

The above sections simply provide illustrations of how the six design variables (factors) can be employed to shape the inter-firm interactions in such a way that they generate the antecedents of alignment. However, while illustrative examples are helpful, a more complete framework for when alignment is needed, and what form it should take, is required. Furthermore, the particular design of specific mechanisms would be aided by the existence of some criteria for testing their utility. The following chapter presents a simple framework for considering the appropriate mix of formal and informal mechanisms, and suggest a simple "utility" test (consisting of questions to be answered with respect to the attributes of the antecedents).

8.0 Application of the Theory

The theory of alignment is able to provide a framework for addressing the following questions in whole or in part:

1) Under what conditions is alignment important for a large engineering project?
2) Does a proposed inter-firm interaction mechanism facilitate the generation of alignment?
3) What outcomes does alignment deliver for large engineering projects?

The following sections will employ the theory of alignment to answer these questions.

8.1 The Need for Alignment

Large engineering projects are socio-technical systems featuring multiple firms operating in concert to deliver complex technical systems. Alignment provides mechanisms to facilitate, and direct, collaborative problem solving and decision making (building the "collective mind") in the face of ambiguity. Alignment supports decision making by providing a common understanding of the problem and possible solutions (the shared cognitive field) and by facilitating the efficient implementation of decisions with potential implications for others (inter-firm trust). The first question above asks "when is alignment important?" A trite answer is “always”. But alignment can be thought of ranging along a spectrum, from “narrow alignment” to “broad alignment”. The real question is what type of alignment is needed?

8.1.1 The Spectrum of Alignment

At one extreme of the spectrum is the form of alignment underlying spot market transactions for commodities. This is “narrow” alignment. The shared cognitive field is formed by the explicit nature of the specified transaction with no associated uncertainty. Inter-firm trust is of the purely calculative type (Williamson 1993); the price mechanism providing reward along with the threat of legal sanction for reneging.[68]

At the other end, we can imagine a situation where multiple stakeholders are ostensibly working together to a common purpose but with different specific (to them) aims under almost complete uncertainty of means and outcomes. This requires very “broad” alignment. (Perhaps democratically elected national governments provide an extreme example of needing such broad alignment). Developing a shared cognitive field requires as complete a set of formal interactions as possible, supplemented by rich (high bandwidth) informal interactions. Likewise the development of trust requires very careful use of formal mechanisms and the frequent deployment of informal mechanisms; all four attributes of trust will be required (competence and reliability, consistency, non-opportunism, reciprocity).

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[68] There is some debate over whether or not this is truly trust (Williamson 1993, Kramer 1999, McAllister 1995). However as many scholars include some notion of calculation in determining trust (Kramer 1999, Zaheer at al 1998, Carson et al 2003) it seems reasonable to suggest that a purely calculative form of trust can exist.

Complex large scale engineering endeavors, for the most part, reside towards the "broad" end of the spectrum. However, within projects, there are instances where narrow alignment is suitable. Indeed, it may be possible for the sponsors of LEPs to make system choices that mitigate the extent to which broad alignment is required.

8.2 Determining the Alignment Needed

The need for, and type of, alignment can be ascertained by considering three dimensions of LEPs that shape decision making: (1) the extent to which the product system's particular properties, constraints and performance requirements have been defined (i.e. the architectural uncertainty); (2) the degree to which the system can be characterized as either exhibiting modular or integral architecture (i.e. the extent to which the system is coupled), and; (3) the "reach" of any decision in terms of the number of distinct organizational units effected by that decision. The first two dimensions are determined by the product system architecture, the third by the organizational and contract designs.

8.2.1 Product System Definition

The first dimension is shaped by the product system architecture. The architectural attributes of; (1) project drivers and constraints; (2) performance specification, and; (3) form specification have varying degrees of uncertainty associated with them. Each attribute also represents a hierarchical level within a system decomposition. The most abstract level (i.e. least detailed or most ambiguous) of system definition is that of the drivers as this establishes the intent and limitations of the system[69]. Next is the system performance specification which establishes the required performance to satisfy the project drivers. The level of definition continues to increase (with consequent reduction in overall ambiguity) with the form specification. This details the physical components/sub-systems required to deliver the performance desired. In simple terms, the system requirements flow down from high level drivers to detailed form specifications (Meier and Rechtin 2002, Blanchard and Fabrycky 1998). At each step "down", the level of detailed knowledge is increased and the aggregate uncertainty is reduced (see Figure 1 below).

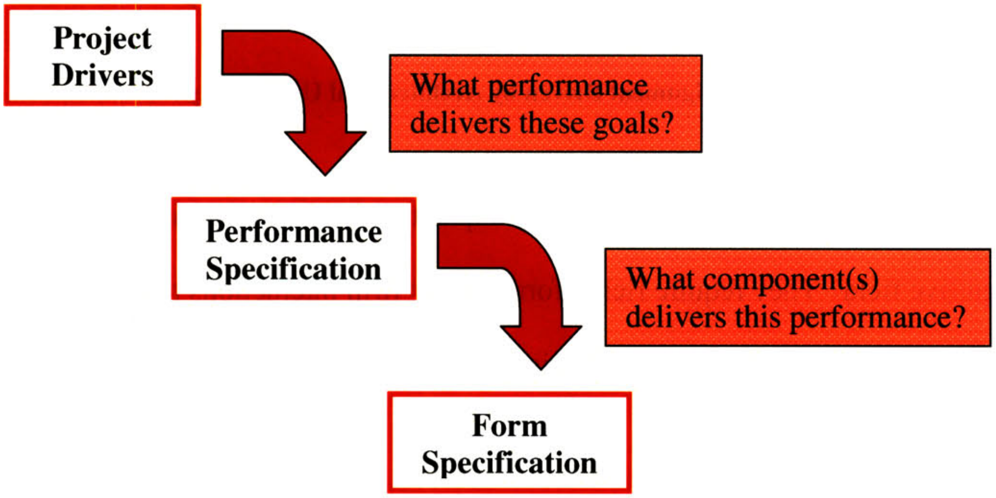

Figure 42: System Requirements Flow Down

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[69] Crawley, E., 2003.

Overall system definition is improved (and thus uncertainty is reduced) as more sub-systems are defined in terms of performance specifications and then form specifications. However, uncertainty continues to exist for each attribute to one extent or another. Each "level" of the system decomposition exists on a continuum of ambiguity and uncertainty; from highly uncertain to completely specified. Thus uncertainty can be determined for the overall system and for each attribute.

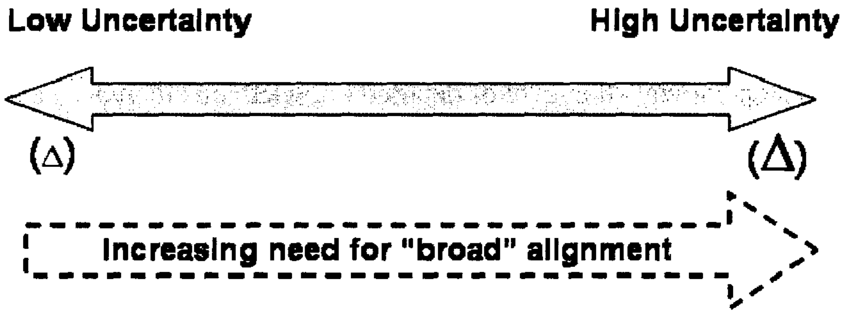

Figure 43: Alignment Driven by Architectural Uncertainty

Systems with high degrees of ambiguity need comparatively more investment in building a shared cognitive field. They require rich informal inter-firm interactions to mitigate the imperfect (due to ambiguity) formal mechanisms.

8.2.2 *Product System Coupling*

The coupling dimension establishes the extent to which any decision related to a product system element impacts other elements of the product system. Large engineering projects (indeed all engineered systems) have architectural properties that can be described in terms of their modularity or integrality. Product systems which feature dependency amongst components or sub-systems whereby "modifications to any one particular component or feature may require extensive redesign"[70] can be described as integral. We can consider the degree of coupling at the attribute level. Does, for example, a change in the form specification of a particular sub-system require changes in components it interfaces with? Thus our product system architecture can be described in terms of the degree of coupling evident.

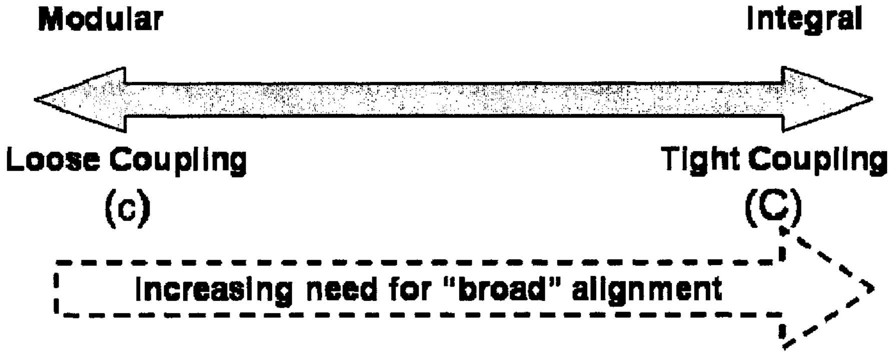

Figure 44: Alignment Driven by Architectural Coupling

Systems with high degrees of coupling (are more integral) need comparatively more investment in building a shared cognitive field. They require rich informal inter-firm interactions to mitigate the imperfect formal mechanisms (resulting from the inability to predict interactions among tightly coupled systems with possibly emergent properties).

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[70] Ulrich K, T., Eppinger S, D., 2000, pp 184

8.2.3 The "Reach" of Decisions

Consider a project which requires the use of multiple firms to deliver the product system. The "reach" of a decision – the extent to which the outcome of a decision taken by one firm effects other firms – is shaped by the organizational design and the contract design, along with the underlying system architecture. The reach of a decision is determined firstly by the partitioning of the system architecture into discrete scopes of work. The organizational design then allocates the scopes to various contractors (firms) along with decision rights and finally the contract design enacts the allocation of these scopes and decision rights. The reach therefore of any decision is a function of the coupling of the system, and the number of discrete firms[71] that are responsible for elements of the system. We can consider the reach of a decision narrow if it is constrained by coupling or by the number of firms affected.

The number of firms is important as each contractor brings their own goals and constraints to the project. As we saw earlier, these need to be incorporated into the shared cognitive field if alignment is to be supported. Thus, fewer firms and looser coupling allows for more narrow alignment. However, a tightly coupled system with multiple firms implies a need for broad alignment.

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[71] This discussion restricts the idea of reach to that of discrete firms. This is because the focus for this thesis is on inter-firm alignment. In reality we can think of reach in terms of within firm organizational units. The implications are similar.

Table 9: Reach of Decisions

	Few Contractors (n)	**Multiple Contractors (N)**
Modular System Architecture (c)	• Reach of decisions narrow	• Reach of decisions may be broad within elements managed by multiple firms. • Reach of decisions may be narrow at the module boundaries
Integral System Architecture (C)	• Reach of decisions may be broad	• Reach of decisions broad

8.2.4 Determining Alignment

The self-enforcing alignment mechanism is built through the informal and formal inter-firm interaction mechanisms. The informal interaction mechanisms are particularly important in providing the means to resolve ambiguities not addressed by the formal mechanisms (and thus contribute to building the shared cognitive field and inter-firm trust). We can use this proposition from the theory of alignment, and the decision dimensions described above, to determine the mix of formal and informal mechanisms needed on a project. And, in so doing, establish the type of alignment required; narrow or broad.

We can place degree of product system architecture coupling and definition into a 2 X 2 matrix to help frame the design choices to be made. Obviously projects exist as a continuum along both axes (as shown above), rather than in four discrete boxes, but the intent is to suggest a broad framework that provides some "first order" guidance.

Table 10: Dimensions of a Project's System Architecture

	System Architecture Well Defined (▵)	**System Architecture Poorly Defined (Δ)**
Modular System Architecture (c)	• Loose Coupling • Well Defined	• Loose Coupling • Poorly Defined
Integral System Architecture (C)	• Tightly Coupled • Well Defined	• Tightly Coupled • Poorly Defined

The theory of alignment, particularly proposition two, provides guidance for determining the appropriate mix of formal and informal inter-firm interaction mechanisms. The table below indicates the outcome of applying the theory:

Table 11: System Architecture Coupling and Definition with Implications for use of Formal and Informal Alignment Mechanisms.

	System Architecture Well Defined (▵)	**System Architecture Poorly Defined (Δ)**
Modular System Architecture (c)	• Formal may be Sufficient	• Formal and Informal within boundaries required. • Formal possibly sufficient across system boundaries.
Integral System Architecture (C)	• Mostly Formal within system boundaries, supplemented by Informal. • Formal and Informal required across system boundaries.	• Formal insufficient, within and across firm boundaries. • Informal mechanisms are critical within and across boundaries.

As can be seen, broad alignment is needed to a greater or lesser extent in three out of four quadrants. Projects which are well defined and have modular architecture may be the only case in which narrow alignment is sufficient. The reason for this is as follows. Well defined product systems (i.e. the product system has clarity of scope with unambiguous drivers, performance specification, system decomposition and interdependence across boundaries), which also have modular architecture (i.e. the interfaces amongst components are discrete and changes to one component do not cascade through the system) can be described completely in the formal contract. Projects in this quadrant correspond more closely to a spot market transaction: a well specified and certain good to be exchanged at a specified price.

The other three quadrants require some mix of formal and informal mechanisms, that is, broad alignment; the more uncertain the system architecture (and hence the less likely that formal mechanisms are complete), the greater the need for informal mechanisms to manage that uncertainty. Highly coupled systems likewise rely on informal mechanisms, in conjunction with the formal, to manage the unanticipated interactions amongst the system elements.

Table 11 above provides a simple framework for answering the first of the three questions posed at the start of this chapter: under what conditions is alignment needed for a large engineering project? Table 11, along with Table 9, also suggests that project sponsors may have design choices available with respect to shaping the need for broad alignment. Choices can be made with respect to the partitioning of the system into discrete scopes of work, and the allocation of that work to contractors. Some subsystems may be able to be established with limited interfaces to others and with authority for that system allocated to a single firm.

This holds forth the opportunity to design discrete areas of the project where narrow alignment is sufficient. Furthermore, given the challenges associated with generating broad alignment, a sponsor may choose to devote resources towards gaining greater definition of a system, perhaps in order to ultimately manage it as a set modular units and again maximize the use of narrow alignment. Alternatively firms may make a tradeoff between project definition and moving forward with the project rapidly. The framework above then directs the sponsor towards making significant efforts to building broad alignment based on informal interaction mechanisms and the careful design of formal interaction mechanisms in support. The second question from the start of this chapter then follows naturally: Does a proposed inter-firm interaction mechanism actually facilitate the generation of alignment?

8.3 Designing Inter-firm Interaction Mechanisms

I have highlighted the need for the firms engaged on LEPs to design formal and informal interaction mechanisms that build shared understanding and inter-firm trust. I have provided illustrative examples of mechanisms that work and those that do not, drawn mostly from my interviews with practitioners. While these examples are (hopefully) helpful in guiding practitioners, it would be useful if I could offer some prescriptive, or normative, rules for the use of the six design variables (the six factors; system architecture, organizational design, contract design, risk, metrics, incentives). However, given the variety of projects, the unique circumstances of each, and the multiple stakeholders involved - each with idiosyncratic perspectives - a prescriptive approach to the design of the inter-firm mechanisms will have limited utility if it is general enough to cover the broad LEP landscape. Instead I will outline a process, based on the theory of alignment and drawing upon tools already established in the oil industry, for designing (and assessing) policies that shape the inter-firm interactions with the aim of building of alignment.

8.3.1 Alignment Design and Policy Testing

The process for planning alignment actions and policies is based on the strategic scenario planning approach used as a management tool in the oil industry (Wack 1985, Schoemaker 1995). The mechanics of the process are enumerated below and shown graphically in Figure 45. The design, assessment and sustainment of alignment actions or policies is, I contend, a negotiated process among stakeholders. It is only through an inclusive process that builds shared understanding and trust within itself (and thus is legitimate) can we expect to generate policies that genuinely deliver alignment across the project.

The steps or stages of the alignment planning and assessment process are:

1. Begin with an assessment of the project context (including an assessment of the six factors; system architecture – coupling, definition, boundaries, organizational design – allocation of authority, resources etc)

2. Identify the stakeholders
3. Identify key uncertainties (about the policies themselves and possible policy outcomes)
4. Test the policies against the antecedents of alignment (described in section 8.3.2)
5. Test the policies for the desired mechanism interactions (described in section 8.3.2)
6. Check for internal consistency and contradictions among policies
7. Propose changes or updates to policies where appropriate
8. Iterate through the proceeding steps

This process can also to be used for determining the usefulness of proposed policies in combination.

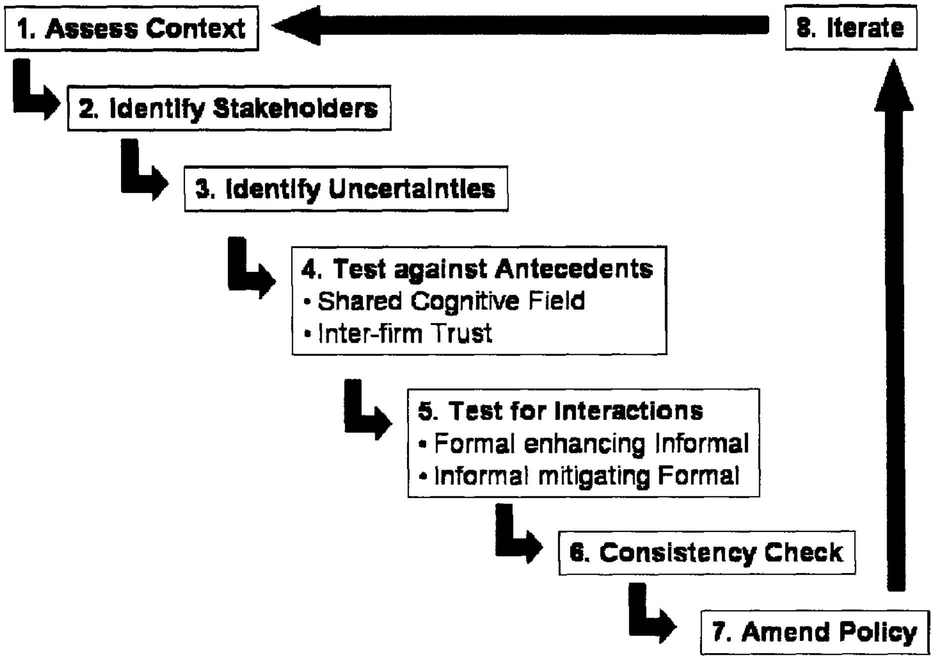

Figure 45: The Alignment Planning and Assessment Process

The six factors are used to decompose the problem space and the alignment process is used to "step through" the policies associated with each factor in turn. The six factors can be used as "lenses" through which to view the construction of alignment, with each considered in terms of the formal and informal mechanisms needed to generate the antecedents. The process provides a structured approach to tackling the challenge of building and sustaining alignment. The mechanics of the process are similar to that employed by established strategic management tools such as scenario planning (Wack 1985, Schoemaker 1995). This has the advantage of being a familiar process to many LEP practitioners.

8.3.2 Testing the Utility of Interaction Mechanisms

Inter-firm interaction mechanisms should be designed to facilitate the generation of alignment. These mechanisms are built via the six factors. With a theory of alignment explicitly stated we now have the opportunity to use this theory not just as an explanatory tool, but also as a design tool. We can test proposed actions employing the six factors for their ability to deliver the requirements of alignment. The process, outlined in Section 8.3.1, is centered on asking focused questions that reveal potential flaws and inconsistencies. Steps 4 and 5 focus explicitly on the antecedents of alignment and the interactions among the formal and informal mechanisms.

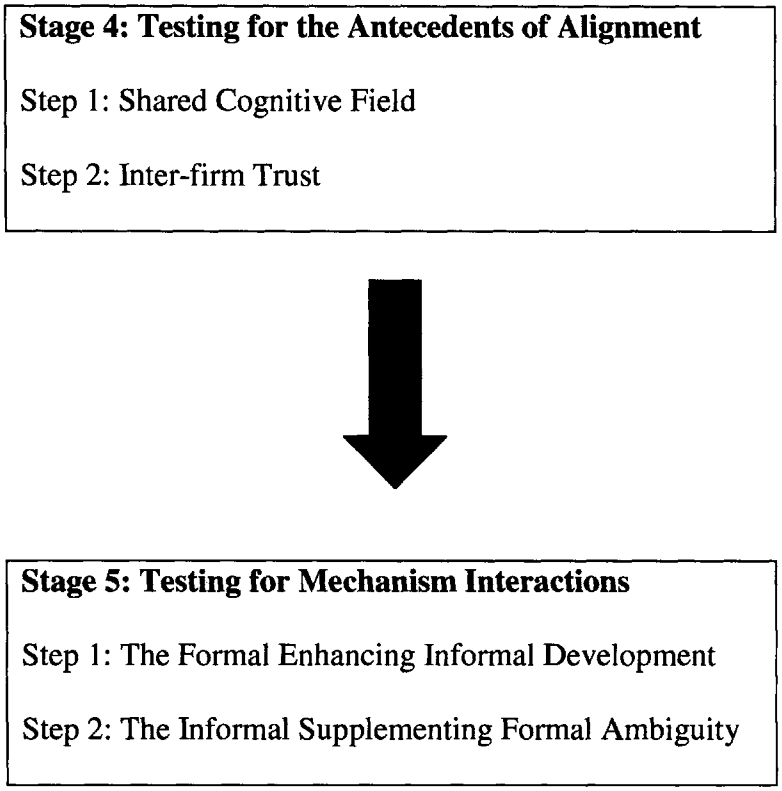

Figure 46: Two Stages of Alignment Planning

It is envisioned that the testing process takes place in group settings with multiple stakeholder perspectives being represented. Alignment is a negotiated process and the process of designing it reflects this. The process is conducted in reference to the context of a specific project. Alignment theory specifies attributes of both the shared cognitive field and inter-firm trust. We can evaluate proposed actions in light of these.

Stage 4 asks of each proposed policy, and in reference to the six factors; (1) does this policy build understand of a shared cognitive field? And; (2) does this policy support the generation of inter-firm trust? Each question is focused on the specific attributes. Negative responses, or uncertainty with respect to effect, reveals the need for further analysis. The attributes of the two antecedents are shown below:

Stage 4: Testing for the Antecedents of Alignment

Step1: Shared Cognitive Field
Does this Policy Build:

- Understanding of objectives and constraints?
- Understanding of tasks and boundaries?
- Understanding of uncertainty and coupling?
- Understanding of decision heuristics?

Step 2: Inter-firm Trust
Does this Policy Build:

- Competence and reliability?
- Consistency of behavior?
- Confidence of non-opportunism?
- Display reciprocity?

Figure 47: Questions Focused on Specific Alignment Attributes

Stage 5 focuses on the interaction between the formal mechanisms and the informal mechanisms. Chapter 7 classified the attributes of the six factors (attributes that serve as the design variables) into those suitable for building formal or informal mechanisms. In this step of the alignment design process we evaluate the policy in terms of how it meets the requirements of the second proposition of the theory of alignment. Essentially we evaluate; (1) does a formal mechanism enhance the development of informal mechanisms? And; (2) does the informal mechanism provide a means for dealing with imperfect formal mechanisms?

Stage 5: Testing for Mechanism Interactions

Step 1: The Formal Enhancing Informal Development

Does the Policy:

- Enable the use of informal mechanisms?
- Motivate teams to use informal mechanisms?

Step 2: The Informal Supplementing Formal Ambiguity

Does the Policy:

- Address the imperfections of the formal mechanisms?
- Conflict with aims of the formal mechanisms?

Figure 48: Questions Focus on Interactions among Formal and Informal Mechanisms

8.3.3 A Worked Example

I will present an example using the two test stages of the multistage "alignment planning" process. The example is fictitious but realistic. It is based on project and firm practices highlighted by informants in my interview set. Consider a policy designed by the sponsor of an LEP to control cost growth. In the face of the possibility (almost certainty) of a proposed project experiencing significant cost growth a sponsor has proposed the following policy to help address this risk. The policy uses the design variables of organizational design, metrics and incentives.

The sponsor has determined that change orders typically account for 15% of the cost growth experienced by their large projects. Their response to this is to centralize approvals of change orders in a dedicated procurement group that overseas all projects. The procurement specialists within this group are measured against benchmarked targets for the overall cost increase attributed to change orders. Incentives are tied to these targets. The perceived benefits of this arrangement are:

- Specialized attention on the issue of change orders. Practitioners are able to learn from each other and bring their combined experience to bear.
- Staff motivated to deliver cost savings to the company. Achieving of results generates savings for the sponsor and returns for the individuals.
- Aggregate scale. The sponsor is able to, possibly, negotiate deals with contractors on the basis of more than one project enabling a bit of room for trade-offs. (This benefit is not explicitly linked to having a centralized process, but it makes for improved efficiency in managing the process of delivering the aggregate scale.)
- Departmental efficiency.

On paper this policy looks quite reasonable. However, testing this policy by considering its implications strictly in terms of the antecedents of alignment reveals some potential flaws. First, consider how it builds the shared cognitive field. Two questions stand out.

- Does it build a shared understanding of the project drivers and constraints? Removing oversight of change order approval from the project team inhibits the team's understanding of the project constraints.
- Does it build a shared understanding of the decision heuristics? The separation of authority clearly limits the ability of the project team, both sponsor and contractor

alike, to gain clarity of how decisions with respect to change order approvals are made. Even if the procurement department is located in the same building as a project the loss of association between team and non-team personnel impedes communication (Allen 1977).

Next, consider the impacts of this policy on inter-firm trust.

- Does this policy support confidence in consistency of behavior? The policy does not support the generation of consistent sponsor behavior from a contractor's perspective. Contractors deal day to day with the project team, but then deal with a procurement department that is focused on cost constraint. The incentives applied to the procurement staff will generate a "cost justification" approach that leads, potentially, to change orders being automatically challenged. This may be very a different behavior from the sponsor project team which is trying to get the job done.
- Does this policy support the generation of reciprocal behavior? For similar reasons to those outlined above, the policy would not. The potential "cost justification" approach would certainly damage the sponsor's ability to display trust to the contractor – and to expect it in return.

Finally we apply the mechanism interactions test.

- Does this formal policy (involving allocation of decision rights, incentives and metrics) enhance the development of informal inter-firm interactions? Establishing a separate functional group for approving change orders risks hindering communication among the project team and consequently the development of informal interactions. Information exchange is slowed by the transfer of authority to outside of the team (particularly if the procurement professionals are tasked with managing more than one project). Slow information transfer can de-motivate investment in communication activities.

The analysis above reveals that, despite the "on-paper" appeal of the policy being proposed, it suffers from notable shortcoming with respect to the building alignment. The theory, and the testing process outlined, suggests that an alternative approach should be taken. The theory of alignment, featuring the dynamic reinforcing mechanism, suggests that the best way to limit the cost impact from change orders is to invest as much as possible in building positive alignment. An alternative policy for the procurement staff could be:

- Locate a procurement function within the project team to shorten communication paths and enable the procurement professionals to make decisions in the context of the project.
- Provide rewards for the procurement team that are linked to the same performance metrics for the rest of the project team.

As a final note in relation to the proposed policy, the set of actions being suggested may indeed have provided an optimal solution for a set of small scale, simple projects that required only narrow alignment. In this instance accumulating resources for efficiency would probably be appropriate.

8.5 The Outcomes of Alignment

Finally, I turn to the third question posed at the beginning of this chapter; what outcomes does (or should) alignment deliver for large engineering projects? It is the central argument of this thesis that alignment provides mechanisms to facilitate, and direct, collaborative problem solving and decision making. Large engineering projects are distributed problem solving enterprises. Success requires multiple firms with hundreds (possibly thousands) of engineers to work together to efficiently create extremely complex product systems. A sequential set of activities in the manner of traditional small scale product development is not practical in this environment, thus work is carried out concurrently amongst tightly coupled systems. Alignment is required to enable the distinct firms to work together to achieve success.

Projects which achieve alignment amongst the distinct firms should, if the theory holds, deliver projects in an efficient and timely manner. An expected outcome of achieving alignment would then be projects that are delivered on-time and on-budget. We can state this first expected outcome as a testable hypothesis.

H1. Projects which achieve alignment experience less cost overruns and delays than those which do not achieve alignment.[72]

This thesis does not test this hypothesis formally (or the ones listed below). However, consistent with a theory building approach, I offer some observations in support of the hypothesis in section 8.5.1 below.

As we saw in the dynamic simulation model a lack of investment in integration activities leads to increased variation orders and costly disputes. Alignment endeavors to create a context that facilitates investment in integration activities. We should therefore expect that for projects where alignment has been achieved the project will experience fewer change orders. Thus the second outcome of alignment can be stated as a testable hypothesis.

H2. Projects which achieve alignment are subject to fewer variation order claims than similar scale and complexity projects which do not achieve alignment.

Again, this hypothesis may be difficult to test as projects are subject to both endogenous and exogenous factors that can generate change orders. A project with good alignment may still be subject to exogenous events (action by NGOs, local or national government decisions, weather) that require changes. However, *ceteris paribus* we should expect fewer variation

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[72] An alternative framing of this hypothesis uses the NPV (net present value) of the project as it includes timing of first oil, operability and other factors not captured by an assessment based purely on cost and schedule.

orders, as the aligned firms discover and resolve potential errors *before* they result in significant changes (and thus claims) to any party.

Where changes do occur, whether through endogenous or exogenous factors, we should expect that any such changes are resolved more amicably in an aligned environment than in a misaligned project. Within an aligned project variation orders should be resolved more quickly and with less use of arbitration or the courts. Again, stating this as a testable hypothesis:

> H3. Variation orders, or claims for changes, on a project that has achieved alignment will be resolved more smoothly and with fewer instances of recourse to 3rd parties than projects without alignment.

Each of these hypotheses makes a statement of expected outcomes for projects with alignment. We can also expect some distinct outcomes for firms engaged on the project. Specifically, the firms who have been engaged on a project that featured alignment should be expected to be inclined to want to work together in the future. However, the nature of the oil and gas industry is such that with few firms in the market place, even acrimonious relationships are a relatively small hindrance to working on the next project.

8.5.1 Hypothesis Quasi-test.

Formally testing the hypotheses stated above is beyond the scope of this thesis. However I will offer observations from the research that are relevant to hypothesis 1, even if they are not "proof". Hypothesis 1 suggests that projects which achieve alignment experience improved performance relative to misaligned projects. A simple first order test would be to compare two similar scale projects, featuring the same set of sponsors and contractors, but where one of the projects appears to display the attributes of alignment and the other does not. We would expect the "aligned" project to perform better than the "non-aligned" project. My sample of projects investigated included two such projects.

The *Norse* project was established as an Alliance and had significantly different outcomes from the *House* project, which was set up as part of MPCS. Both projects were established with the intent of achieving best-in-class performance for the design, fabrication and installation of technically challenging facilities, using "win-win" approaches to contracting. And while in different geographic regions and water depths, they were of a similar scale in terms of capital expenditure (approximately $1.2 billion) and, arguably technical complexity. Both had the same sponsor firm and employed many of the same contractors (although with some notable differences). The *Norse* project however was completed on schedule and under budget ($200 million saved), while *House* was behind schedule (6 months) and approximately $400 million over budget.

Norse displayed many of the attributes of alignment. For instance, the *Norse* project developed a well defined system architecture (building strong foundations for a shared cognitive field) in response to the particular challenges of the field. *Norse* was a collection of marginal fields with a complex set of independent operators of those fields. It was subject to significant study as various concepts were developed to enable a viable development option to emerge. The Alliance structure, with shared payoff and risks amongst contractors, encouraged a collaborative approach amongst the firms (building both a shared cognitive field, and inter-firm trust through structures such as the Alliance governing board). Each contractor bid on the amount of downside (and hence upside) they were willing to expose themselves to, after they were awarded contracts, but before the Alliance was finalized. This process encouraged firms to accurately assess their "control" over various aspects of their individual scopes. As it turned out, the system integrator, a large engineering contractor, took on a higher proportion of the risk (relative to the formal scope they were being compensated for) as they had the best knowledge about the integration of the work.

The Alliance was also set up with a formal oversight board formed from the various contractors in order to facilitate dispute resolution and speed efficient transfer of information (building the cognitive field). The board met weekly and during these meetings any problems, delays, emerging risks were discussed. This process was crucial, according to the Project General Manager, to "building trust among the different companies and a shared sense of the team". Teams were collocated where possible and the project manager for the sponsor and prime contractor shared office space and a secretary (building trust and understanding). The *Norse* project, it can be argued, successfully built a self-enforcing alignment mechanism.

House, unfortunately, did not. As we saw in the case study, the project failed to build alignment. The generation of shared understanding was inhibited on a number of fronts: the project team was spread around Houston and elsewhere, project drivers were changed a number of times and were not communicated effectively, the product system was not well defined when commitments were made between firms. The project lacked both well developed formal (e.g. system architecture) and informal (e.g. oversight of contractors – too many cooks) mechanisms and experienced a number of acrimonious contract disputes with key contractors. It is therefore not a surprise, based on my understanding of alignment, that the project experienced significant delays and cost overruns. The comparative case studies of *Norse* and *House* offer some support for the notion that alignment delivers improved project performance.

As a side note, the success of *Norse*, and other early alliance projects, prompted a belief in the oil industry in the 1990s that this form of contractual arrangement was the solution to the problem of building alignment and the threat of cost overruns. It turned out to be a false dawn. Several alliance projects in the years that followed experienced the usual problems of massive cost overruns, poor operational performance and project delays. In the case of the Schehallion FPSO project in the North Sea, the alliance agreement was abandoned during the project and a more traditional approach adopted in response to escalating costs. I have not investigated these other alliance projects in depth, but from some preliminary conversations and archival research, it appears that these projects failed because the formal mechanisms of the alliance contract came to be relied on at the expense of the informal mechanisms. An attitude of "as long as we share risk and reward" the project will be a success was short sighted. The alliance contract form is open to the problem of free-riding and opportunism. In addition, once it becomes clear that performance targets are likely to be missed the risk of having to share the loss generated by other firms generates defensive and adversarial relationships among contractors.

9.0 Conclusion

Large engineering projects are socio-technical systems featuring multiple firms operating in concert to deliver complex technical systems. The central argument of this thesis is that alignment provides mechanisms to facilitate, and direct, collaborative problem solving and decision making. Large engineering projects are distributed problem solving enterprises. Success requires multiple firms with hundreds (possibly thousands) of engineers to work together to efficiently create extremely complex product systems within an environment of high uncertainty. Alignment is required to enable the distinct firms to work together to achieve success.

The alignment theory provides a framework for practitioners to approach the problem and gain some initial traction. Developing alignment is about creating a socially structured field in which the individuals, and the firms they represent, come to understand and internalize a shared set of decision making premises in conjunction with building trust based approaches to interactions. Alignment based on this approach is more likely to be robust in the face of unexpected system perturbations that one relying on firm's (and individuals) calculative self interest.

The theory provided a set of frameworks that enables project sponsors to evaluate a system in terms of the appropriate mix of formal and informal mechanisms, and the allocation of decision rights. The six factors (system architecture, organizational design, contract design, risk, metrics and incentives) provide levers for the practitioner to employ in designing systems (both technical and organizational) for alignment. Attributes of each were highlighted and their contribution to alignment discussed. A formal mathematical model was employed to demonstrate the interdependencies amongst the alignment factors and existing theories of intra and inter organizational behavior engaged to provide insight and validation.

9.1 Contribution

My research aimed at generating a theory of alignment makes a contribution in the following areas:

1. My research brings together two streams of literature in organizational studies; (1) the nature and utility of trust within firms, and; (2) cognition and decision making within firms. It synthesizes these mostly separate domains into a causal structure that provides an explanation for the bimodal performance of large engineering projects.
2. It offers a theory for the performance of large engineering projects. Project management (arguably a subset of organizational theory) has largely been devoid of rigorous theoretical underpinnings (Shenhar 1998, Kloppenborg and Opfer 2002). My research begins to address this gap in the literature.
3. It extends, and applies, the theories of high reliability organizations to a new context; that of multiple firm enterprises. In doing so the research provided evidence of the

possibility of achieving "collective mind" in broader contexts than previously considered.

4. It provides empirical qualitative evidence of the existence and application of formal and informal contracts between firms in support of the theoretical work of Baker, Gibbons and Murphy.
5. The theory, and the frameworks developed from it, offer practitioners insight into the objectives to be sought when designing the socio-technical aspects of large engineering projects. This thesis unpacks a complex real world phenomenon and provides a simplifying theory through which to view the problem space.

9.2 Future Work

There are a number of directions in which to take this research. Firstly, the propositions that form my theory need to be empirically tested. The hypotheses posed in Chapter 8 present suitable starting points. Being able to test a theory of alignment for projects is itself a step forward in the domain of project management literature. Next, the work could be extended by relaxing some of the limiting assumptions that frame the research. For example, it would be interesting to see to what extent the theory remains useful in an environment featuring not-for-profit firms. I suspect that the underlying self-enforcing mechanism will prove to be fairly resilient in alternative settings, but the design variables will need to be adjusted.

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Appendix A

A.1 System Dynamics Model for Doctoral Research

The system dynamics model used for this research is largely the same as the model built for my Masters research at MIT. That model and its underlying assumptions are described in my Masters thesis (McKenna 2005). The model was updated for the doctoral research with a number of changes that reflected increasing knowledge of the project environment and new approaches to building insight from the model. There were three substantive changes to the version used for my Masters research:

1. The variable *Benchmarked VO Cost* was added to capture the sponsor's expectations based on past experience of project cost increases driven by contractor submitted variation orders. I was able to use quantitative archival data to support the value selected for the model.

2. A revised formulation for the *Relationship Index* (RI) was developed. The revised formulation was now based on the variable *Sustained Schedule Pressure*'s effect on the RI and the ratio of VO costs accrued on the project to the benchmarked (expected) VO costs (see above) captured by the variable *Actual VO Costs to Benchmarked VO Costs*. The previous formulation had included the ratio of actual staff on the project to the expected (planned) staff on the project as a factor in determining the RI. Research

had revealed that it was not entirely evident that an increase in actual staff against planned staff was by default an impediment to sustaining a good relationship. In fact in some circumstances the sponsor preferred contractors to respond to schedule pressure by "manning up", i.e. taking on more staff. The new formulation for the composite variable is:

Average RI = (Schedule Pressure RI + VO Pressure RI)/2

Where *VO Pressure RI = f(Expected Variation Order Revenue /Benchmarked VO Costs)* and;

Schedule Pressure RI = f(Sustained Schedule Pressure)

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".

3. The third substantive change involved a re-casting of how the *Fraction Time on Integration* influences the *New Work Defects Fraction.* The previous formulation used a table function to modify a *Typical New Task Correct Fraction* according to how much time was actually spent on integration compared with the ideal (needed)

time spent on integration activities (the variable *Ideal Fraction Time on Integration*). A flaw in the previous formulation was that even for project which required almost no time on integration (i.e. they are very simple modular systems) reducing the time spent on the integration (in reference to the ideal) could have significant impacts on the error rates for all tasks. This formulation was not sound in extreme cases, and indeed failed to reflect the reality "on the ground". A simpler has been adopted. The revised formulation also strengthens one of the assumptions underlying the work. The percentage of new tasks designed correctly first time is now:

The New Work Designed Correctly Fraction = ((1-Ideal Fraction Time on Integration) + Fraction Time on Integration)

This formulation instantiates the following assumption: errors occur because of a failure to invest in integration (a failure to build a shared cognitive field). Where tasks are simple and have no need for building understanding the engineers can "get them right" first time. Of course this is not strictly true, as errors can and do occur in even simple projects with modular architectures. However, for the purposes of this model this revised formulation provides mush more robust results. For example, a very simple project with an *Ideal Fraction Time on Integration* = 0.1 would generate an error rate of 0.9, if no time is spent on integration, and 0.95 if half the ideal time is spent. A complex project with an *Ideal Fraction Time on Integration* = 0.4 would generate an error rate of 0.6 if no time is spent on integration and 0.8 if half the ideal time were spent.

A number of other small adjustment and revisions were made but with no material impact on the models output or behavior. The changes above strengthened the model making it more robust under extreme conditions testing (Sterman 2000) and also delivered model behavior that more fully reflected the range of behaviors exhibited by projects in reality. The full model documentation is included in appendix A.3

A.2 Model Simulation

The model was simulated for a range of exogenously determined agreed engineering rates and a range of exogenously determined ideal amount of time to spend on integration activities. These two independent variables established (1) the agreed contract price, and; (2) the project complexity.

Simulating Alternative Contracts

The agreed engineering rate is established via the *Margin Accepted on Contract* variable. This is multiplied with the *Preferred Return Hourly Rate* (set at $100/eng*hr) to establish the *Contracted Hourly Engineering Rate*. The model project was simulated across a range of accepted rates from $60/eng*hr to $130/eng*hr.

Margin Accepted on Contract	*Contracted Hourly Engineering Rate* ($/eng*hr)
0.6	60
0.7	70
0.8	80
0.9	90
1.0	100
1.1	110
1.2	120
1.3	130

Simulating Alternative Product Systems

The model project was also simulated across a range of *Ideal Fraction Time on Integration* values. This variable serves as a proxy for project complexity with more complex projects requiring *ceteris paribus* more time spent on integrating the subsystems. The range of values reported in the thesis were from *Ideal Fraction Time on Integration* = 0.1 to *Ideal Fraction Time on Integration* = 0.5.

Ideal Fraction Time on Integration
0.1 (Standard Project)
0.2
0.3
0.4 (Base Case – Complex Project)
0.5

The sets of simulations were combined to establish an 8 X 5 matrix of 40 discrete runs with final project costs and delays for each. The base case (complex project) data reported in the thesis was for a project with the *Ideal Fraction Time on Integration* = 0.4. The data for the standard project simulation used an *Ideal Fraction Time on Integration* = 0.1.

The contractors preferred return on a given project (*Contractor Preferred (Typical) Profit Margin*) is established by the *Break Even Hourly Rate* variable. For the simulations referenced in the thesis the break even hourly rate (i.e. the rate needed to cover fixed and variable costs without profit) was $70/eng*hr.

Simulating Shocks to the Project

The simulated project was exposed to a shock event in the form of scope changes midway through the project. The variable *Percent Increase of Tasks Due to Scope Increase* established the size of the scope increase (acting as a multiplier of the value of *Initial Project Tasks*) which was input into the stock of *Project Tasks to Do* using a PULSE function. The timing of this shock could be adjusted via the variable *Time of Scope Change*, and the rate at which the scope was adjusted via *Time to Approve Scope Change*. The parameters used for the results reported in the thesis were:

- *Percent Increase of Tasks Due to Scope Increase* = 0.2 (i.e. 20% Increase in number of tasks)
- *Time of Scope Change* = 100 (i.e. change introduced at week 100, half way through the original schedule)
- *Time to Approve Scope Change* = 1 (i.e. the new work scope is delivered to the contractor as a complete package over 1 week)
- *Ideal Fraction Time on Integration* = 0.4 (i.e. the base case of a "complex project" was reported)

A.3 Model Documentation

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

Work Remaining=
        Project Tasks to Do+Task Rework+Tasks Completed for Approval
        ~       Tasks
        ~       The oustanding work is nominally the initial tasks minus the tasks \
                completed
        |

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
        |

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

Effect of VO Ratio on VO Pressure RI(
        [(0,0)-(10,1)],(0,1),(0.25,0.98),(0.5,0.92),(0.75,0.85),(1.10092,0.754386),(2,0.5),(\
                3,0.25),(4,0.15),(5,0.1),(10,0.1))
        ~       Dmnl
        ~       Table for the effects of value of VO generated compared with expected VO \
                Costs\!\!
        |

RI Effect Time=
        IF THEN ELSE( Average RI>Relationship Index , Time to Update RI Increase, Time
to Update RI Decrease\
                )
```

```
	~	Week
	~	Time to adjust the RI
	|

Effect of Sustained Schedule Pressure on Schedule Pressure RI(
	[(0,0)-
(10,1)],(0,1),(0.5,1),(0.75,1),(0.978593,0.986842),(1.15,0.95),(1.34557,0.846491\

	),(1.5,0.75),(1.75,0.5),(1.98777,0.368421),(2.5,0.3),(3.3945,0.241228),(5,0.2),(5,0.2\
		),(10,0.2))
	~	Dmnl
	~	Function that maps input (sustained schedule pressure) to relationship \
		index effects\!\!\!
	|

Average RI=
	(Schedule Pressure RI+VO Pressure RI)/2
	~	Dmnl
	~	The average of the RI Effects
	|

Schedule Pressure RI=
	Effect of Sustained Schedule Pressure on Schedule Pressure RI(Sustained Schedule
Pressure\
		)
	~	Dmnl
	~	Schedule pressure effects the RI. This variable captures the discrete \
		effects of sched pressure
	|

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

VO Pressure RI=
	Effect of VO Ratio on VO Pressure RI(Actual VO Costs to Benchmarked VO Costs)
	~	Dmnl
	~	The Relationship Pressure created by the cost of VOs
	|

New Work Defects Fraction=
```

```
        ((1-New Work Design Correctly Fraction)/defect to task ratio)*SW Defect Switch
        ~       Defects/Tasks
        ~       Percent of new work tasks that are designed with defects
        |

Actual VO Costs to Benchmarked VO Costs=
        (Expected Variation Order Revenue/(Max(1,Benchmarked VO Cost)))*SW VO Ratio
Impact on RI
        ~       Dmnl
        ~       Ratio of the actual VO costs being asked for by the contractor against the \
                benchmarked average VO costs
        |

"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 Work Design Correctly Fraction=
        ((1-Ideal Fraction Time on Integration)+Fraction Time on Integration)
        ~       Dmnl
        ~       The percentage of new tasks that are designed correctly based on the ideal \
                integration time. Low ideal numbers means that tha project is simple and \
                most tasks do not require integration and thus can be designed correctly \
                first time
        |

Estimated Initial Defect Fraction=
        1-Typical New Task Correct Fraction
        ~       Defects/Tasks
        ~       Estimate of defects based on previous experience (0.15)
        |

Benchmarked VO Cost=
        Project Lump Sum Price*Benchmarked VO Percentage of Sanction Cost
        ~       $
        ~       Expected (Benchmarked) cost of variation orders
        |

Benchmarked VO Percentage of Sanction Cost=
        0.17
```

```
        ~       Dmnl
        ~       From studies, the percentage of sanction costs that VOs average. (Data \
                from IPA indicate a range of 13 - 18%)
        |

Estimated Staff Required=
        INTEGER(((Estimated Engineering Hours Required/"Task Define-Development Eng
Hours for Project Schedule"\
                )/Unit Lead Engineer)*(1+Initial Overhead Engineering fraction))+1
        ~       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 anectdotal \
                evidence.
        |

SW Scope Increase Switch=
        1
        ~       Dmnl
        ~       Swicth to turn on the project scope change
        |

Time to approve scope change=
        1
        ~       Week
        ~       Time for sponsor to approve changes to scope. A variable for dimensional \
                consistancy
        |

Initial Project Tasks=
        10000
        ~       Tasks
        ~       Initial number of tasks to be completed on the project
        |

Scope Change Rate=
        (PULSE( Time of Scope Change, Time to approve scope change)*Initial Project
Tasks*Percent Increase of Tasks due to Scope Increase\
                )*SW Scope Increase Switch/Time to approve scope change
        ~       Tasks/Week
        ~       Project Scope Increase at a defined point in time. As a percentage of the \
                initial tasks
        |
```

```
Percent Increase of Tasks due to Scope Increase=
        0.2
        ~       Dmnl
        ~       Multiplier to establish the incrase in the scope for the project
        |

Time of Scope Change=
        100
        ~       Week
        ~       The week in which the project sponsor elects to change the scope
        |

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.
        |

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, bassd on agreed Price and Initial task numbers
	|

Percent Increase in Project Cost to Sponsor=
	((Project Sponsor Cost-Project Lump Sum Price)/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 Varaiation Orders generated over the project - a \
                cumulative total of Invoices
        |

VO Invoice Generation=
        Variation order generation
        ~       Tasks/Week
        ~       Rate at which variation orders are generated
        |

SW TCA Sched Press=
        0
        ~       Dmnl
        ~       Switch to include Taks 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
        ~       Inicated 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.
        |

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=
        1
        ~       Defects/Tasks
        ~       Under "ideal" conditions (i.e "Ideal Fraction Time" of time on \
                integration) it is expected that 90% of New Tasks are correctly delivered \
                first time. This variable is used to calculate the contractors expected \
                staff and bid price for the project.
        |

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 Profiability 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 \
		profitablility 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 Oportunity 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 vraiation 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) 1.5 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 mot \
		making any profit there is no desire to hire staff.
	|

SW Switch for Profit Multiplier on Hiring=
	1
	~	Dmnl
	~	Swicth to trun 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 ecah 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 expeted 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
        |

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.
        |

New Task Engineering Hours Required=
        Estimated Initial Work/Normal Task Productivity
        ~       engineer*hour
        ~       Engineering hours required to complete designs of the initial tasks
        |

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=
0.7
~ Dmnl
~ Multiplier applied to the Preferred Hourly rate to derive the rate used \
for the Contacted Rate. This is a measure of the firms aggesiveness to win \
the work. More aggresive 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 Decrease=
        8
        ~       Week
        ~       When RI is decreasing the update time is shorter
        |

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 capicity 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
        ~       Swicth 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 to calculate the actual fraction time \
		spent on integration.
	|

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 expetced 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\!\!\!
	|

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 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.
	|

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 beal 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 \
		aniticipated 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 oustanding 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
	|

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 CheckingTasks 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
	|

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
        ~       Taks 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=
        200
        ~       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 themsleves.)
|

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.
        |

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

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 themsleves.)
        |

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 themsleves.)
        |

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  = 450
        ~       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.
        |
```