Executing Major Projects through Contractors

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Abstract

Project based organizational structures are utilized in many industries. The firms engaged in these endeavors, project sponsor and contractor alike, risk both capital and reputation in the market-place with each new project. The relationship between project sponsor and contractor influences the outcome of the project to a significant extent. Complex and challenging projects are made more so by the adversarial relationships that frequently exist between the sponsor and contractor(s). This paper presents a model for examining the influence of the contractor/sponsor relationship on the execution of a project. The focus is on the effects of the relationship, as determined by the financial performance of the engaged firms and key project performance indicators (schedule, budget etc), on the degree to which the firms engage with each other and the impact this has on project performance. Analysis of the model indicates the importance of appreciating the project's need for effective team integration in determining the financial arrangements.

1. Introduction

Project based organizational structures are utilized in many industries and exist on many scales. At one end of the spectrum a “project team” may simply be a few individuals within a firm assigned to solve a specific problem. At the other extreme a project can involve thousand of individuals, employed by dozens of firms, spread across the globe, acting together to deliver a particular outcome over the course of several years. Examples of the second type of project are to be found in industries such as aerospace/defense (for weapons system development, satellites, etc) and the energy sector (for infrastructure developments such as offshore oil and gas platforms, refineries etc). These projects are often described as Large Engineering Projects or LEPs. One element that tends to characterize LEPs is their use of contracted firms to effect execution. While many small projects are executed by teams that exist within a single firm, LEPs typically involve a number of firms being brought together, through contract structures, by the project sponsor to execute the project.

This research investigates the role that formal contract relationships between firms play in determining major project outcomes. The following premises frame the investigation:

1. Many product systems being developed through major project structures (utilizing contractors) can be identified as integral systems (as compared to modular architectures).
2. Integral systems require significant investment in integration activities (specification development meetings, design reviews etc) in order to be successfully developed.
3. Motivation for sustaining investment in integration activities is developed through relationships between agents (firms, individuals) based on trust and mutual goals.
4. The firms engaged in a project organization will act to create value (as they perceive it) for their shareholders.

These four premises when taken together can lead to unexpected outcomes. The need to create shareholder value can generate adversarial relationships between the project sponsor and contractor. This damages trust based relationships and undermines the investment in integration activities, leading to sub-optimal project execution.

This research builds a formal model to investigate the mechanisms described above. The research adopts the methodology of a case study and adds formal model building. A case study of a recent major project undertaken by an integrated energy company was conducted. A formal model was then developed that captures the dynamics of project development and includes explicitly the relationship between project sponsor and contractor. This paper presents the formal model.

2. Conceptual Background

The study of project based organizations, and the mechanisms that drive project performance in general, has generated a rich literature that cuts across a number of academic disciplines including organization theory, economics, product development and system dynamics. This research draws upon aspects of that literature. This paper presents an overview of some of these knowledge domains and establishes the linkage between the existent theories in the appropriate knowledge area and the assumptions outlined in the introduction.

Premise 1: Oil and Gas platforms are integral product systems.

This research limits its investigation to projects that feature integral product systems architecture, such as offshore oil and gas facilities. The case study investigated a large oil and gas infrastructure project, which I assert featured a product system with integral architecture. The relevant literature provides a number of alternative definitions for integral architectures that support this characterization. Integral systems are those that are "designed with the highest possible performance in mind"[1] and where "modifications to any one particular component or feature may require extensive redesign".[2] Another definition of integral systems architecture has been offered that relates to the decomposability of the system by function: in integral architectures functions are spread across components resulting in more complex interfaces (Sosa, Eppinger and Rowles, 2000). Finally, an alternative perspective of the product system's architecture is provided by consideration of the system requirements from a mass and power transportation view. Whitney (2004) suggests that certain physical systems, typically mechanical ones that carry significant power, are constrained from utilizing modular architectures.

The oil and gas facility developed by the project under investigation featured a large offshore platform that incorporated production, drilling and accommodation modules. This type of facility, in addition to producing hydrocarbons at pressures that can exceed 10,000psi and 200F, drills for reserves at depths of over 20,000ft below the earth's surface. The facility as a whole must be designed and constructed to withstand hurricane force wind and wave loadings while remaining on station in water depths of over a mile. An inspection of the engineering complexity involved with developing such a system reveals an architecture that satisfies the definitions of integrality enunciated above.

Premise 2: Integral systems require integration activities during development.

The integral nature of the systems being development has important implications for the development process. As Novak (2001) points out "the more interconnected are the parts of a system, the more difficult it is to coordinate development"[3]. Communication between, and within teams, is essential for the successful development of complex systems. Wheelwright and Clark (1992) have emphasized the importance of

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[1] Ulrich K, T., Eppinger S, D., 2000, pg 184.
[2] Ibid.
[3] Novak s., Eppinger S, D., 2001, pp 190.

communication with respect to improved project performance. As stated by Eppinger (1997); "To assure that the entire system works together, the many sub-system development teams must work together".[4] Communication and information sharing is central to the development of integral systems, "team members deal with imprecise information and so must communicate to define problems or to reach consensus on the solution of a problem".[5] The literature thus certainly supports the notion that successful projects require significant investment in critical integration activities that are characterized by communication and information sharing. Examples of these critical integration activities includes inter-team meetings such as design review meetings, systems integration meetings, specification development meetings and a host of others. It is therefore necessary to ask; what are the requirements for establishing this investment?

Premise 3: Sustained integration efforts require team trust and mutual goals.

A number of elements are needed to support the required communication. For example, 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."[6] 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."[7] Investigations into the phenomena of virtual and distributed teams have also noted the importance of trust in generating the communication that is vital for project success. A recent study by McDonough III et al, (2001) into the use of globally distributed product development teams noted that "low levels of trust can have detrimental affects on the quality of communication and interpersonal relationships."[8] Trust becomes particularly important as a function of complexity. McAllister references Thompson (1967) in observing that "under conditions of uncertainty and complexity, requiring mutual adjustment, sustained effective coordinated action is only possible where there is mutual confidence or trust."[9]

Two principle forms of trust can be described: cognition based trust, grounded in individual assessments in relation to peer reliability and dependability, and affect based trust, grounded in notions of reciprocity founded by personal care and concern (McAllister 1995). In either case "reliability and dependability expectations must usually be met for trust based relationship to exist and develop, and evidence to the contrary provides a rational basis for withholding trust."[10] A project using contractors for execution provides ample opportunities for expectations not to be met. For example, a contractor falling behind schedule, or increasing the cost of a project through variation orders (sometimes known as change orders), can be interpreted as failing to meet the reliability and dependability expectations of the project sponsor.

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[4] Eppinger S, D., 1997, pp 199.
[5] Sosa M, E., Eppinger S, D., Pich M, McKendrick D, G., Stout S, K., 2002, pp 46.
[6] Keller R, T., 1986, pp 723.
[7] McAllister D., 1995, pp 24.
[8] McDonough III E, F., Kahn K, B., Barczak G., 2001, pp 112.
[9] McAllister D., 1995, 25.
[10] Ibid, pg 26.

Premise 4: Firms engaged on the project will act to create value for their shareholders.

Projects are mechanisms for delivering value to the project sponsor and contractor alike. The project sponsor has initiated the project in order to generate value from the product system being developed, whether it be through the sale of the product itself, or in the case of an oil platform, from the sale of the hydrocarbons that the product system delivers. For most projects the ultimate NPV delivered is affected by the development costs of the product system. Project sponsors will typically be mindful of these costs and seek to minimize them.

Contractors create value by charging sponsors for their particular skills and services. The cost of the project is thus determined, in part, by the cost associated with meeting the contractor's fees. It is often assumed that contractors will, *ceteris paribus*, want to maximize their profits by charging as high a fee for their services as they can. Sponsors will naturally want to contain these costs. In creating the project enterprise the sponsor and contractor will establish a formal contract which stipulates the contractor's scope of work, the sponsor's expectations and the project's financial arrangements.

What System Dynamics tell us about projects.

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).

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

- Lack of adequate front end loading.[11]
- Unrealistic schedules.
- Staffing. Either inadequate or poorly timed.
- Over use of overtime.
- Poor governance (Miller and Lessard 2000).
- Poor processes. (i.e a lack of clearly defined requirements, reviews, metrics)

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

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

distinct from staff engineers, or that there are not distinct phases of activities in a project (Ford and Sterman 2002, Black and Repenning 2001, Repenning 2001). Indeed a key behavior of the projects under investigation in the system dynamics literature has related to the impact of allocation of resources to different phases of the project. Rather the assumption of "under one roof" relates to the notion that the project model is contained within the boundary of one firm or enterprise. Divergent financial incentives between actors engaged in project execution have not been explicitly included previously. This research addresses this gap in the literature.

3. Why variation orders cause problems.

It is important to recall an assumption stated above: the firms will act to create value (as they perceive it) for their shareholders. For the contractors the creation of value is achieved through a variety of contractual mechanisms. The first is the agreed rates or lump sum value of the project. The project sponsor and contractors agree a price for provision of services, the scope of services being set out in the contract documents. A second mechanism for deriving value from the contract is the use of variation orders. This mechanism is provided in contracts as, for all but the most trivial of projects, there is uncertainty surrounding the scope, particularly for complex product system development projects. This allows for changes to be made to the contract scope and additional costs calculated.

Contractors are able to use the variation order mechanisms to generate additional revenue from the project. In very large and complex projects there usually exists a certain unavoidable amount of ambiguity to the contractual terms. It is almost received wisdom amongst project sponsors that the contractors use variation orders as a primary source of revenue. The variation order revenue mechanism can be described by the causal loop below.

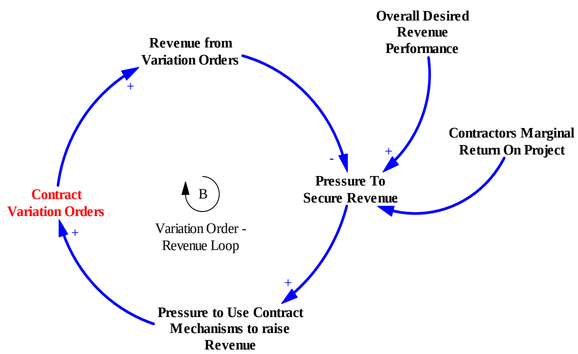

Figure 1. Variation Order – Revenue Loop

When a gap exists between the contractor's desired financial performance 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 the number of VOs increase, revenue is generated from the project. This helps to close the gap between expected and delivered financial performance.

Of course, the use of variation orders does not just deliver revenue. Other consequences exist.

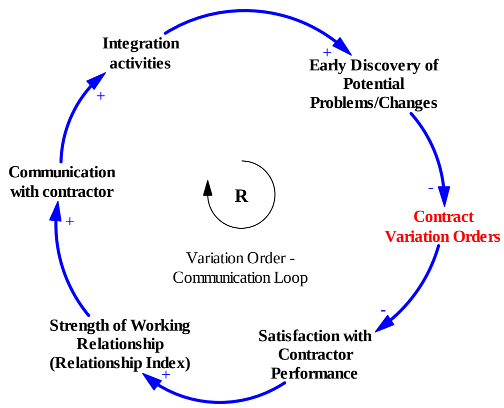

Figure 2. Variation Order - Communication Loop

VOs generate additional project cost for the sponsor and when used are likely to reduce the level of satisfaction 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 time and *on budget*. VOs usually hamper that ability. Satisfaction with the contractor's performance is correlated with the strength of the working relationship between the contractor(s) and the sponsor. As the relationship is damaged by the VOs, the incentive to invest in trust based processes such as communication is diminished.

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

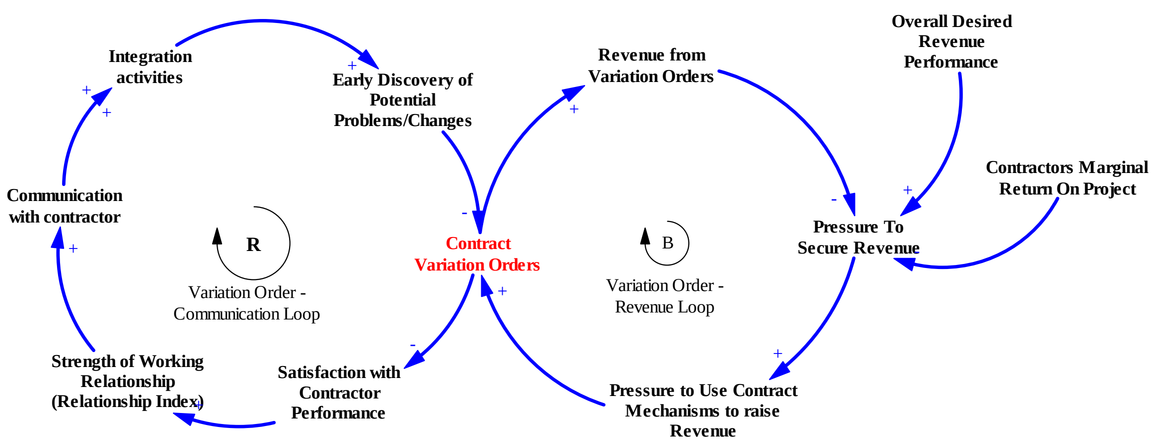

Figure 3. Variation Orders: A Linking Mechanism

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

More work means less resources (time, people) are available to invest in time consuming activities such as the critical integration processes. The consequence of that remains as described earlier. Here again we see that the use of variation orders in fact leads to, again, more errors and more variation orders. However, the impact of variation orders does not end here.

A further consequence is that pressure builds to service this additional work load through the acquisition of additional resources. From the contractor's perspective the ability to staff the project has been determined, in part, by the terms (profit margins, value of the bid etc) agreed for the original contract. Bringing more personnel onto the project requires a budget to support that decision. This can lead to additional pressure on the contractor's project team to deliver revenue to help pay for the additional resources the variation orders generated. It is clear that once we put all of these feedback structures together the decision to use variation orders has a number of consequences for the execution of the project.

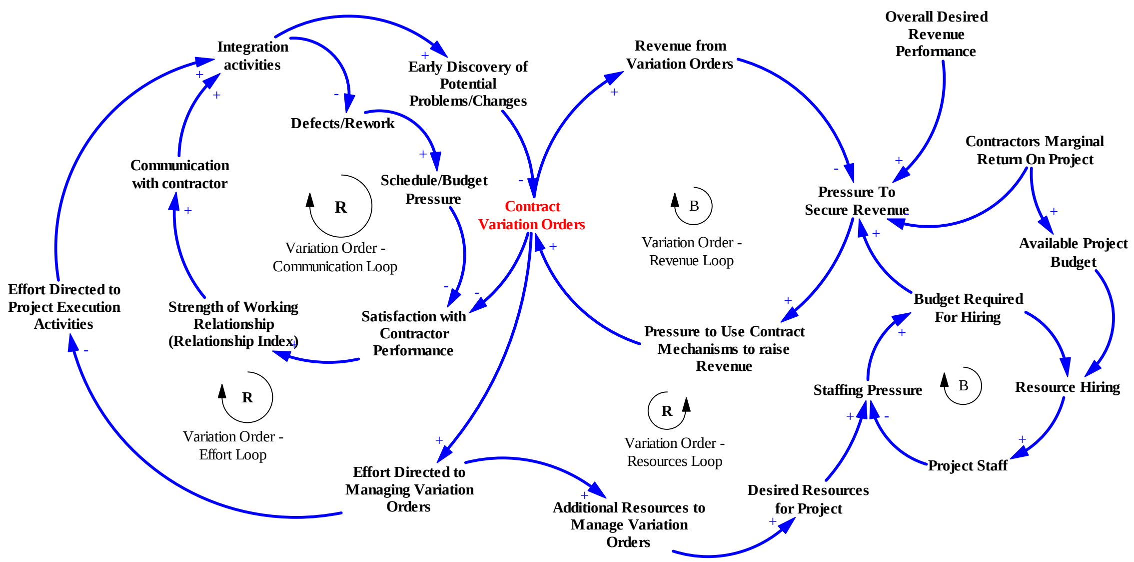

Figure 4. Variation Order Feedback Mechanisms

4. Project Model

4.1 Overview

A key structure in most project models is the rework cycle[12]. This structure was first developed by Pugh-Roberts Associates in relation to the Ingalls Shipyard claim and it has subsequently been revised and refined through many different applications (Abdell-Hamid 1991, Repenning 2001, Ford and Sterman 1998, 2002). The rework cycle constructed for this paper is illustrated below. It differs from the structure employed by Ford and Sterman (1998), amongst others, in eliminating the stock of *Unknown* or *Undiscovered Rework*. This removes a delay in processing and executing the rework tasks, making the project model more efficient (thus making the model conservative in its behavior) while maintaining the essential feature of distinguishing between work to do, work completed correctly and rework.

The model adds the variation order cycle. Tasks with defects move either to the stock of *Task Rework* or *Variation Orders Submitted*. The *Variation Order Generation* rate establishes the percentage of tasks with defects that will be resolved through the formal variation order process. Variation orders are then approved as rework tasks and move to the stock of *Task Rework.* A certain percentage of these *Variation Orders Approved as Rework Tasks* also generate new tasks which enter the stock of *Project Tasks to Do* at the rate of *V.O New Task Generation Rate*.

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

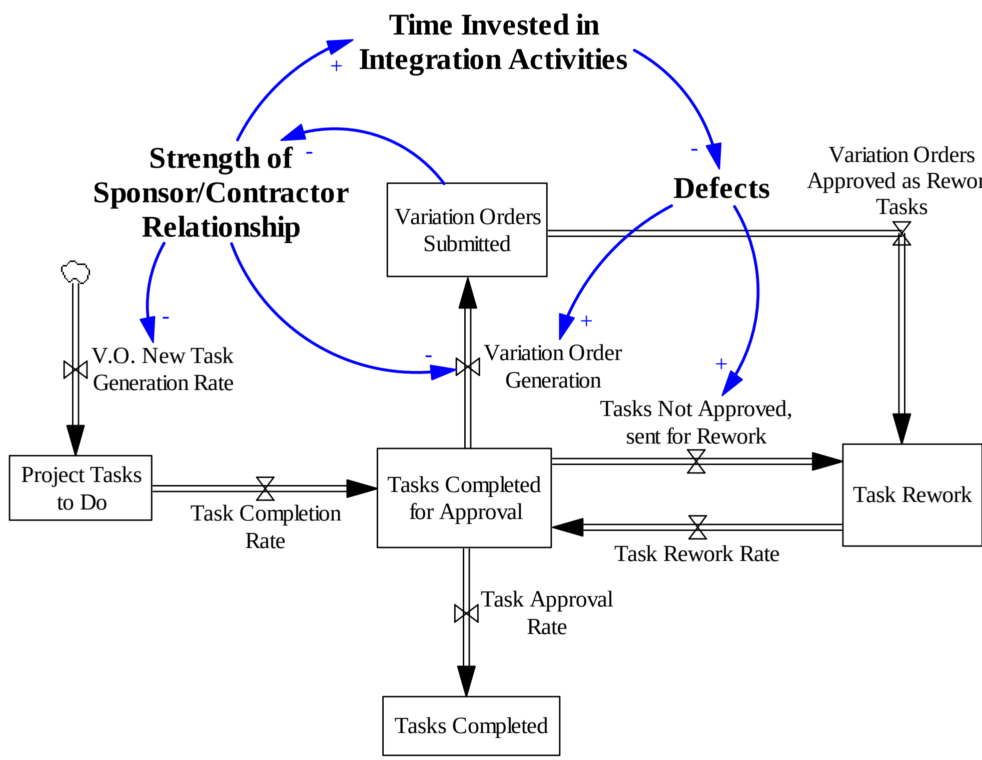

Figure 5. Contract Model Rework Cycle

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

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

$D_f = f(T_i)$, where D_f is the *New Work Defects Fraction*
T_i is the *Fraction Time on Integration*

Variation orders also directly impact the relationship between project sponsor and contractor and the financial performance of the project (each variation order represents a claim by the contractor for more money). The model measures the financial performance of the contractor and this determines in part the *Percent of Rework Tasks submitted as Variation Orders by Contractor, Desired Full Time Staff* and the *Initial Full Time Staff*. Completing the key structural elements of the model is the *Relationship Index*. This composite variable captures the strength of the working relationship between the sponsor and contractor and is a function of the *Sustained Schedule Pressure*, the *Actual Staff to Planned Staff Ratio* and the *Actual VO to Expected VO Ratio*.

Indicated RI = 1/*(VO Pressure*Sustained Schedule Pressure*Actual Staff to Planned Staff Ratio)*

Where *VO Pressure* = f(*Variation Order Invoices/Expected Variation Orders*)

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".

The model is simplified with respect to some of the feedback structures developed in previous project models. The effects of overtime and staff fatigue are not included, and nor are issues related to inexperienced staff (a "rookie" fraction). Schedule pressure however is included. Leaving out some of these well understood mechanisms is thought to, if anything, minimize the effects of the variation order- communication loop. Including the effects of fatigue and staff inexperience would only exaggerate the effects of poor communication on project performance.

4.2 Model Assumptions

The model is based on the assumption that the relationship between the project sponsor and the contractor is established by the lump-sum contract agreed to at the outset of the project. In other words, the model does not capture inter-firm relationships that include cross-ownership mechanisms, profit sharing structures, joint-ventures, long-term supplier relationships or similar. It is quite common for project sponsors to use a competitive bidding process for lump-sum contracts as a means to select contractors. This approach has been thought of as a mechanism through which the project sponsors can control project risk and minimize the cost of the project, enhancing expected NPV.

The model includes a number of assumptions which reflect policy decisions made by both the contractor and project sponsor. These assumptions are critical in determining the model behavior and reflect the insights gained during interviews with senior project managers conducted for the case study. A key assumption is that contractors will devote time and resources to variation orders ahead of other project tasks. Variation orders represent an opportunity to generate additional income for the contractor, over and above the agreed contract. It follows that resources will be devoted to these activities as a priority:

Task Development Define Capacity = Work Capacity from Full Time Resources-VO Generation Effort Drain

Where *Work Capacity from Full Time Resources* is the number of design tasks/week that the contractor can attend to based upon resources (number of engineers) available, their productivity, the level of effort each task requires and the current work week. The capacity to do development tasks (*Task Development Define Capacity* i.e the design and engineering associated with completing the project) is determined by first diverting resources to generating variation orders.

While generating variation orders are a priority for the contractors, the sponsor does not approve them instantaneously. Each variation order is tracked, audited and deliberated over by both the contractor and the project sponsor. This all takes time and during this time resources are devoted to the process by both parties.

The model divides the remaining work capacity between integration activities and task completion. Integration capacity (C_I) is determined by the *Fraction Time on Integration.* As discussed previously the amount of time devoted to integration activities is a function of both the schedule pressure the contractor is under and the strength of the working relationship.

*Fraction Time on Integration = MIN(1, Ideal Fraction Time on Integration*Integration Time Multiplier From Sched Pressure*Integration Time Multiplier from RI)*

It is assumed that when staff are under pressure to produce work they will cut back on the time they spend attending meetings and design reviews (integration activities) in a bid to work on “productive tasks”, such as producing the deliverables specified in the contract. The strength of the relationship between the project sponsor and contractor also determines, in part, the time devoted to integration activities. When the relationship between project teams deteriorates (whether in response to schedule pressure, or rising numbers of variation orders) the individuals in those teams are less willing to spend time with each other. Thus a poor relationship leads to decreasing time spent in integration activities. In addition, a poor relationship generates willingness to use variation orders. If the relationship has become adversarial between the sponsor and contractor then the contractor will feel justified in trying to “squeeze” the sponsor for more money. The remaining capacity to do work, the *Task Completion Capacity* (C_{TC}), is divided between *New Task Capacity, Rework Capacity* and *Task Checking Capacity*.

Naturally, the contractor will hire/allocate staff onto the project in response to schedule pressure. However, financial considerations also determine the contractor’s response to schedule pressure. A contractor feeling financial pressure will not be as willing to shift staff onto the project or hire externally.

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

5. Analysis and Results

The model was simulated for a range of exogenously determined agreed engineering rates (dollars paid per engineer-hour worked). The model uses endogenous rates of $100/eng*hr as the contractor’s preferred rate and a break-even figure of $70/eng*hr. The range of agreed rates spanned from below the contractor’s cost ($60/eng*hr) to very healthy profits ($130/eng*hr). The model calculates a lump sum cost for the project based on the agreed rate and an endogenously calculated estimate of the staffing required for completion of all project tasks within schedule. This lump sum cost represents the contract value agreed to by the project sponsor and contractor. Total project costs for the sponsor include the lump sum costs and the variation order costs generated during project execution. Variation orders require resources which are frequently priced at a different rate from the agreed lump sum rate and the model reflects this by setting the *Variation Order Engineering Rate* at $150/eng*hr. The sponsor’s project cost does not include the cost of lost revenue incurred by project delays. In reality the “costs” of a delayed new vehicle launch, or delayed production from an oil and gas facility, may far outweigh the costs associated with reimbursing the contractors.

Initially the model was run without the *Relationship Index* influencing contractor behavior. i.e. no impact on *Fraction Time on Integration* or *Percent of Rework Tasks submitted as Variation Orders by Contractor*. The first set of simulations, entitled “Contractors Want Profits”, did include pricing effects on the contractor’s policies for establishing the initial staff level on the project, hiring staff and use of variation orders. As can be seen below the overall project cost to the sponsor is greater than the agreed lump sum across all agreed engineering rates. This reflects the fact that a certain percentage of tasks will be completed with errors (established by the *Typical New Task Correct Fraction*), and of these errors a certain percentage will generate variation orders. This is the case no matter what the agreed rate for no project is perfectly specified or perfectly executed. However, the slope of the project cost line is reduced as the “cheaper” lump sum contracts generate more variation orders.

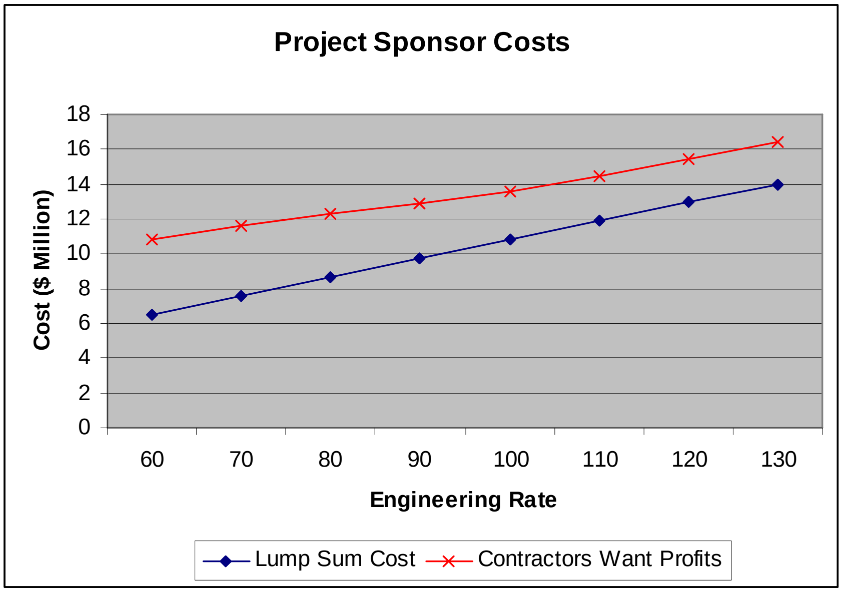

Figure 6.

Of course the pricing effects also included impacts on staffing levels which contributed to the project finishing later for cheaper contracts (contractors use less staff and will delay hiring new staff when they are squeezed by a cheap contract). The effects of smaller than ideal staff, and delayed hiring, on project performance has been well documented, and the results from this model are consistent with previous efforts. The project was originally scheduled to be competed in 100 weeks, however the cheapest contract ends in week 182, while the most expensive project finishes in week 123.

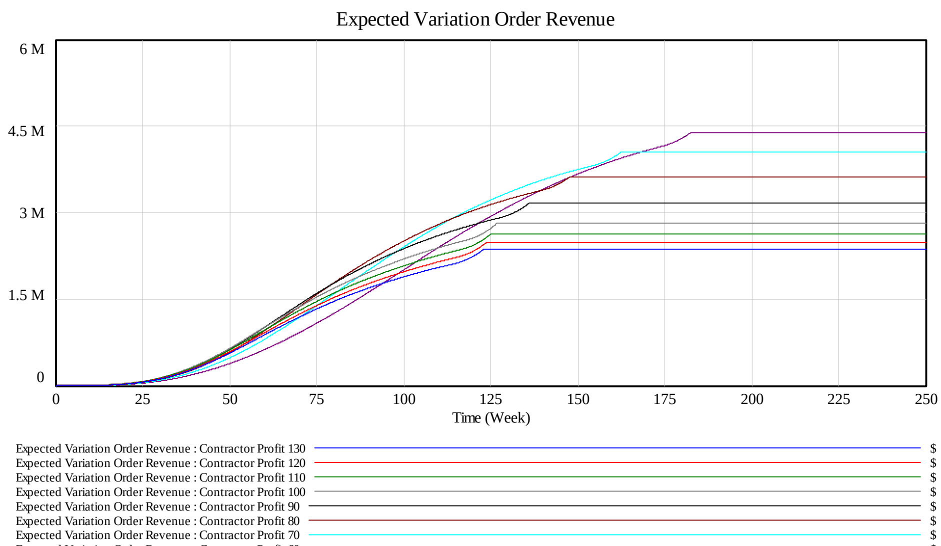

Figure 7.

Including the effects of the *Relationship Index* (the simulation entitled "Relationships Matter") on the contractor's desire to use variation orders, and their investment in integration activities, changed the sponsors project cost. Again we see (Table 1 below) that projects under all contract price ranges are affected by the inclusion of these feedbacks. However, the cheaper lump sum contracts exhibit stronger affects.

Agreed Contract Rate	Project Sponsor Cost ($M)	Project Sponsor Cost ($M)	Completion Date (week)	Project Sponsor Cost ($M)	Completion Date (week)
($/eng*hr)	Lump Sum Cost	Contractors Want Profits	Contractors Want Profits	Relationships Matter	Relationships Matter
60	6.47	10.85	182	22.09	243
70	7.549	11.59	162	21.92	213
80	8.627	12.25	148	21.5	191
90	9.705	12.87	136	21.2	176
100	10.78	13.59	127	20.88	162
110	11.86	14.49	125	21.28	158
120	12.94	15.43	124	21.74	155
130	14.01	16.38	123	22.27	151

Table 1.

Projects executed under higher priced contracts still experience cost growth which can be explained by considering the following. All the projects in the simulation experienced some delays and consequent schedule pressure, as discussed above. Schedule pressure is an input into the *Relationship Index* and thus even those projects executed under high price contracts experience some degradation of the relationship between sponsor and contractor (indeed it could be argued that the fact that the sponsor is paying a premium price would lead to increased antipathy towards a contractor who is behind schedule). The "Relationships Matter" simulations incorporated the effect of this degraded relationship on the use of variation orders and time spent on integration activities. Irrespective of the contract price, a reduction in time spent on integration leads to more defects and more variation orders, further degrading the relationship.

It is most interesting to note however the cost performance of the inexpensive contracts relative to the more expensive ones. The model demonstrated price dependent "tipping point" behavior. The cheaper contracts featured higher levels of cost growth associated with variation orders (see Figure 8 below) and consequently had significantly higher total project costs. Cheaper contracts ended up costing more than the expensive alternatives. This is especially true if the cost of the delayed revenue from the product being developed is included (See Figure 8).

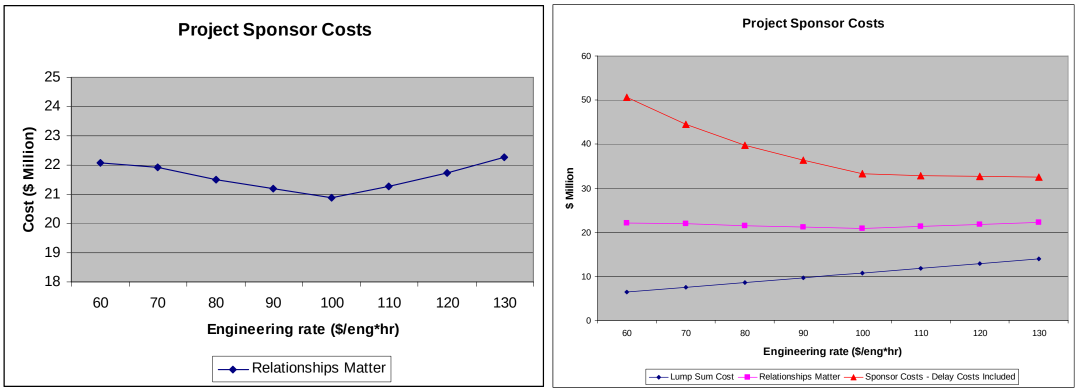

Figure 8.

The delay cost was calculated by assuming a project capital recovery period not exceeding the project development time. i.e the revenue from the product system being developed by the project would generate the cost of the project in under 100 weeks. Each week delay therefore incurred a significant penalty in lost earnings

Devoting sufficient time to integration activities is critical for the success of projects developing complex product systems[13]. In the model this notion was captured by the *Ideal Fraction Time on Integration* variable. The initial value for this established the required amount of time to be devoted to integration activities. In addition the *Ideal Fraction Time on Integration* can be thought of as a rough proxy variable for the complexity of the product system being developed: complex systems will require proportionally more time to be devoted to systems integration than will simpler systems. Carrying out a sensitivity analysis on the project model from the perspective of varying levels of product system complexity revealed the effects system complexity has on the project. As can be seen in Figure 9 below, projects developing more complex systems (i.e with higher ideal integration time fractions) showed more variance in final project costs as a function of agreed engineering rate. The projects developing simpler systems had price outcomes more tightly clustered.

[13] Sosa M, E., Eppinger S, D., Pich M, McKendrick D, G., Stout S, K., 2002,

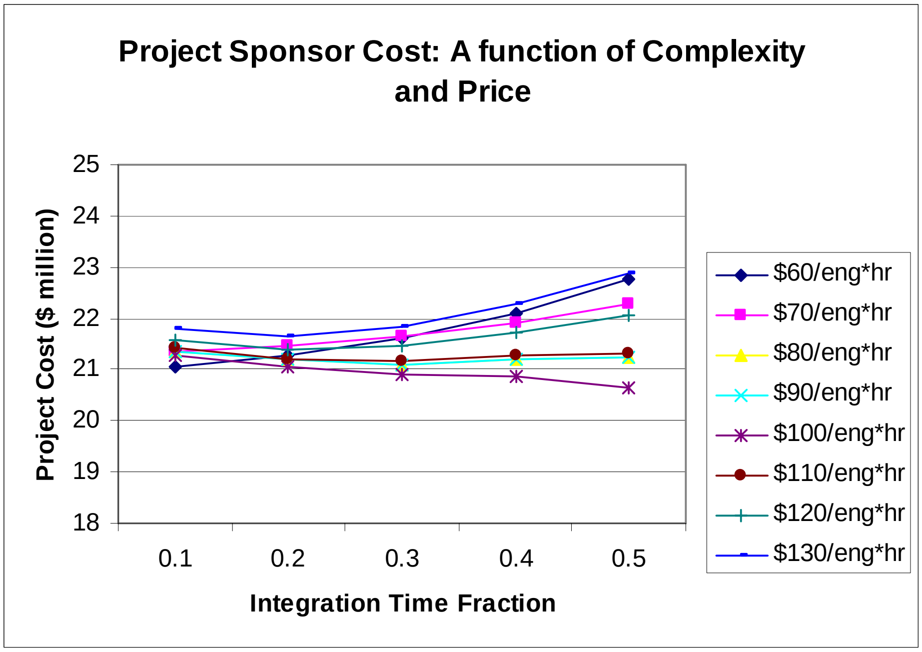

Figure 9.

6. Discussion

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

6.1 Findings

The key findings are:

1. Projects developing complex integral product systems display price sensitive "tipping-point" behavior.
2. Complex projects (those requiring significant integration efforts) are more sensitive to price driven behaviors than simpler architectures.

The price sensitive tipping point, and the influence of product complexity, can be seen clearly in the following figure. The plot shows a three dimensional map of the project space with project costs on the vertical axis. This cost varies as a function of both the agreed contract rate and the project complexity. Projects developing products with “low” complexity (i.e. the leading edge of the plot below) show much less variability in cost outcomes as a function of the engineering rate. By way of contrast the development of “high” complexity systems (the far edge of the plot) shows marked variability and a clear point of inflection.

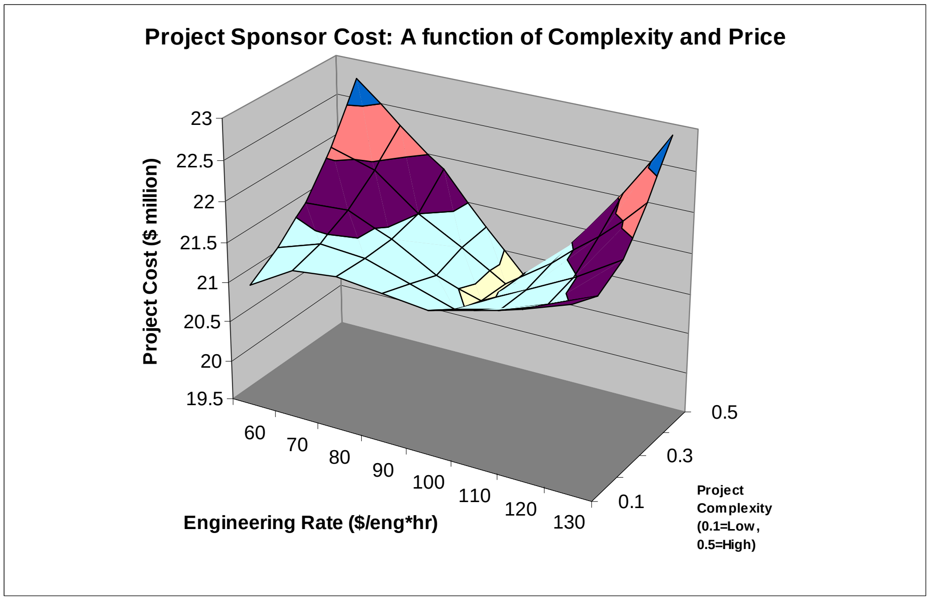

Figure 10.

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

6.2 Multiple Contractors

Most sizeable projects are executed by more than one contractor and the project enterprise usually features a number of engaged firms. The research findings suggest that beyond a price sensitive tipping point project execution becomes increasingly difficult.

The “difficulty” has a number of dynamic cause-effect relationships including a reduction in the time a contractor will devote to integration activities. Consideration of this finding, in conjunction with the environment of networked contractors, suggests the possibility of the project experiencing “contractor contagion”.

If one contractor reneges on investing time and resources on integration activities with the project sponsor it follows that they will also, or are likely to, renege on investing in integration activities with other contractors. Why would a contractor do this? In many projects the contractors have formal contracts with the project sponsor for the delivery of services, but not with other contractors. This has consequences for other contractors working on highly integral systems and invokes the “variation order – communication loop” described in previous sections. As integration meetings usually involve several of the firms engaged on the contract, limiting effort in this area affects their work as well. Through this mechanism we can see how the dynamics investigated by this research could “spread” from contractor to contractor once an initial disruption (the initial reneging) occurs. The idea of “contractor contagion” is analogous to the “fire fighting” dynamic within the single firm, multi-project environment (Repenning 2002), suggesting an opportunity for further research.

6.3 Alignment of Incentives

The findings of the research can also be framed in terms of alignment between the contractor’s and project sponsor’s incentives. Alignment of the incentives between firms is achieved when the risks, costs and rewards of doing business are distributed fairly across the network (Narayanan and Raman 2004). In the model the alignment between sponsor and contractor can be characterized as orthogonal. It can be seen that the firms behave as they do because the financial incentives are not aligned. When project sponsors drive down the initial lump-sum cost of a project, this is clearly at the expense of the contractor’s financial position. When contractors invoke variation orders to secure revenue, this is not in the financial interests of the sponsor. This creates an adversarial relationship which is an essential element of the competitive bid lump-sum contractual relationship. The misalignment between the sponsor and contractor can generate additional expense for the sponsor.

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

7. Implications for Research and Practice

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

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

1 Projects operating in the price sensitive region are essentially unstable in the face of changes. Therefore, a great deal of effort must be put into front end loading (FEL) to ensure that the number of project changes is kept to an absolute minimum.
2 The lowest cost solutions are robust only for simple projects that are not highly integral. For some projects in which the scope is very clear, and unlikely to change, and which represent "standard" applications of technology then a low cost solution may be appropriate.

While the discussion above sets out some steps to deliver effective projects, the winning approach was best summed up by a senior project manager who said while discussing how best to manage projects and contractors:

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

A number of issues were raised by the results that require further research. First, the notion of "contractor contagion" requires further investigation. Virtually all projects of any significance are executed by teams of contractors and it is worthwhile understanding to what extent problems for one contractor transfer to other members of the project team, and how that occurs. Second, alternative enterprise architectures and structures that provide for improved alignment of incentives need research. It is proposed in the next stage of this research endeavor that "alliance" project organizations will be investigated. Alliance organizations, in an energy industry context, often feature an explicit risk-reward pay-off structure to align contractor and sponsor interests. Finally, the impact that integral product system architecture has on project performance and the relationship to appropriate contract structures warrants serious study. As indicated in the results, the level of effort required for integration has significant influence on the project outcome and needs to be included in the determinations for the financial arrangements.

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