The Dynamics of Project Management: An Investigation of the Impacts of Project Process and Coordination on Performance

by

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Abstract

Successful product development projects are critical to competitiveness in several industries. Successful management of these projects requires an understanding and use of the dynamics of projects. Existing research has focused on a static view of project management. This research investigates the impacts of dynamic project structure on performance with a focus on the influence of the development process.

A dynamic simulation model of a multiple phase project was built using the system dynamics methodology. The model integrates several previously developed and tested project structures and adds a separate structure for the development process. Simulations describe the behavior generated by the interaction of customized development project phases and a project management structure. Project performance is measured in time, quality and cost. The model was calibrated to a computer chip development project for a single development phase configuration and a four phase configuration which represented the majority of the development process. Testing revealed that when the model is appropriately parameterized the resulting simulated behavior closely resembles the historical behavior of the project.

The model was applied to the investigation of coordination policies for improved project performance. Analysis of the influences of two descriptors of coordination policy reveal that cycle time can decrease as the delay between coordination labor need and coordination labor provided increases. The model structure helped identify the timing of a shift in feedback loop dominance as the cause of this counterintuitive behavior.

The research finds that development processes significantly impact the dynamic behavior of projects through the feedback, delays and nonlinear relationships which are not used in traditional project models but are important descriptors of project complexity. Expanding the models used to manage projects to include dynamic features requires a change of focus by researchers and practitioners. The system dynamics methodology provides some of the tools for developing and implementing such an expanded project model. Future research using the model within and beyond its current limits can facilitate the development of new knowledge of project dynamics and the implementation of that knowledge in project management practice.

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This dissertation is dedicated

to my father

Griffin Thomas Nelson (1926 - 1956)

and my grandfather

Sylvester Henry Nelson (1895 - 1980)

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Chapter 1

Introduction

1.1 Context

The Bose Corporation needed improved product development performance. Increased competition and customer requirements called for the faster development of better integrated sound system products. So Bose re-engineered the early portion of its product development process for integrated sound systems. Before re-engineering Bose used a functional organizational structure which separated marketing, engineering, and manufacturing into three departments. These departments passed deliverables from marketing to engineering and from engineering to manufacturing with little interdepartmental coordination. Bose applied the Concept Engineering (Burchill, 1992) approach to re-engineer its process and organization to improve quality and reduce cycle time in the face of increased product complexity. Marketing and concept design functions were combined into a new Concept Development group. Conceptual designs and business plans are passed from Concept Development to the new Detailed Design group. Final designs are passed from the Detailed Design group to manufacturing. The flow of products through Bose's product development process was also re-engineered with new deliverables and milestones for the new development groups. Bose expected significantly higher quality products and reduced cycle times from the re-engineering.

However re-engineering the process and organization doesn't completely solve development project performance problems. Re-engineering at many companies appears to have altered the appearance but not the effective content of their product development efforts. Often only one or two performance measures improve (Cooper and Kleinschmidt, 1994). Sometimes performance deteriorates. For example, re-engineered development systems have failed to reduce (Nevens et al., 1991) and have on occasion increased cycle times (Burchill and Walden, 1994; Clark and Fujimoto, 1991a). Bose experienced improvement in the integration of marketing and conceptual design functions by re-engineering. But reductions in cycle time did not materialize. Coordination problems between the Concept Design and Detailed Design groups replaced similar problems between marketing and engineering. For example concept designs were considered unfeasible by the Detailed Design group. Ineffective communication between product developers and management also contributed to coordination problems. Frequent changes in project objectives and available resources reduced development efficiency and increased rework. Re-engineering the product development process and organization had moved these issues from the marketing-engineering interface to the Concept Design-Detailed Design interface. Bose's re-engineering of their process structure may have primarily shifted the location of their coordination problems instead of solving them. These problems prevented Bose from experiencing the hoped-for reductions in cycle times.

What prevented this industry leader renowned for quality and research from gaining the full and expected benefits from a thorough re-engineering effort? What product development components, characteristics and relationships generated counterproductive behavior in well-intentioned product developers? How can the product development process be described and investigated to better understand these issues?

Bringing new products to market which fulfill customer needs is critical to success in open competitive markets (Patterson, 1993). Development projects generate these new products for market introduction. Developing products faster, of higher quality, and cheaper than competitors can increase market share, profit, and long term competitive advantage. This has made the performance of product development projects an increasingly important area of competitive advantage in many industries. For many years development schedules, quality, and cost have been managed primarily with traditional project management tools such as the critical path method. However changes in competitive conditions within the last decade have increased the difficulty of accelerating projects, increasing quality, and reducing costs with traditional project management tools.

Three recent changes in competitive conditions have increased the imperative to and difficulty of improving project performance (Wheelwright and Clark, 1992; Patterson, 1993). First, competition has grown increasingly international, diluting or eliminating geographic protection for many firms. This has forced firms to compete with the best in the world instead of the best in their market area. Globalization of firms has combined with increased access to international markets to make competition more intense, more demanding, and less forgiving of errors. Second, customers have grown more sophisticated and demanding of products. Standards for performance, ease-of-use, and reliability are high and rising. Customers demand increased variety and thereby fragment previously homogenous markets. Third, the pool of technologies used to develop new products is growing. This has increased the number of possible solutions to customer needs and can transform the development process itself.

Many manufacturing firms have adopted a new product development paradigm and re-engineered their product development processes and organizations in response to the challenges of product development (Rosenthal, 1992). New systems such as concurrent engineering and cross-functional development teams have replaced more sequential and functional-based systems to integrate product development efforts and improve performance. Likewise, construction firms are using new technologies such as computer assisted design to accelerate and integrate the development process. These new conditions and approaches have impacted product development in at least three ways. Product development environments have become increasingly dynamic (Wheelwright and Clark, 1992; Nevens et al., 1991). Concurrent development (Clark and Fujimoto, 1991b) and increased awareness of the influence of dynamic relationships on successful project development (Wetherbe, 1995; Iansiti and Clark, 1993; Osborne, 1993; Patterson, 1993; Rechtin, 1991) have increased the role of dynamic effects on project performance. Finally, the number of interdependencies among development activities and participants has increased (Hayes et al., 1988). This has led both researchers and practitioners to recognize the increasingly critical role of understanding the dynamics of projects in managing the development process for success.

While some firms have attributed significant improvements to the adoption of the new paradigm and methods (Merrills, 1991; Nevins and Whitney, 1989) the aggregate results have been mixed

(Iansiti, 1993a; Clark and Wheelwright, 1993; Dean and Susman, 1991). One contributing factor is that these systems require more coordination than traditional processes and organizational structures to develop affordable high quality products quickly (Iansiti, 1993b; Clark and Wheelwright, 1993). This may be because the new paradigm has increased the complexity of the product development process as described above and thereby tightened the constraints imposed by the interdependencies among participants and processes (Ulrich and Eppinger, 1994; Malone and Crowston, 1990). These increased complexities become apparent at the project level where project managers attempt to operationalize departmental designs and policies to develop specific products.

This research investigates the dynamic impacts of product development process structure and project coordination policies on performance. Although model validation will focus on the development process of a specific manufacturing industry (semiconductors) the project structures are common to many development projects. The motivation for the research, problem definition, and model development draw on several industry processes. The applicability of the research framework and results across industries is discussed in the conclusions.

1.2 Motivation for Research

Competitive forces such as intense global competition, fragmented and demanding markets, and diverse and rapidly changing technologies cause companies to view improved product development as a competitive imperative (Wheelwright and Clark, 1992). These forces have increased the complexity and uncertainty of product development. The product development processes and organizations created for relatively stable markets, long product life cycles and project durations, and technology-based competition are often no longer capable of producing products fast enough, inexpensive enough, and of high enough quality to remain competitive (Clark and Fujimoto, 1991a). Entire industries are re-engineering how they develop products (Irving, 1993; Peterson and Hillkirk, 1991).

Therefore improving project performance may not be as simple as it first appears. Well-intentioned changes to the development process can cause severe unintended side effects (Thomas and Napolitan, 1994; Jessen, 1992). An example using the increase in headcount to improve schedule performance follows. These effects can be amplified by time delays and nonlinear relationships among project components (Cooper, 1993b). Part of the cause of the difficulty lies in the internal structure of the development process (Richardson and Pugh, 1981; Roberts, 1974) and the coordination policies used to manage the product development activities and resources (Hoedemaker et al., 1994; Iansiti and Clark, 1993; Fujimoto et al., 1992). Companies which experience difficulty coordinating their development efforts also have long cycle times (Clark and Fujimoto, 1991a). Those which coordinate well also have short cycle times (Takeuchi and Nonaka, 1991; Clark and Fujimoto, 1991a). Iansiti and Clark (1993) found that more internal integration (coordination) was positively related to performance as measured by quality, productivity, and lead time in the development of automobiles. As a specific example, Bose experienced difficulties in coordinating the work of the Concept Design and Detailed Design groups (Ford et al., 1993). The Concept Design group needed assistance from the Detailed Design group to meet the review and approval standards set by management for Concept Design deliverables. Concept Design found it difficult to obtain this assistance from Detailed Design before the hand-off because management had not approved the Concept Design deliverables and therefore had not authorized Detailed Design to work on the project. This created a circular problem for the Concept Design group: it needed Detailed Design help to get approval and needed approval to authorize Detailed Design to help. Detailed Design also experienced coordination difficulties with the re-engineered process and organization. Conceptual product changes continued after Concept Design had given the project to Detailed Design. These changes required unanticipated coordination by both groups and rework of designs by Detailed Design. Another problem was that the priorities of Concept Design, Detailed Design, and management were not aligned. In one case the misalignment of goals resulted in a severe lack of shared ownership in two projects by different groups of developers. This generated project sabotage and the failure of both products to pass Concept Design reviews and receive approval to continue development. The misalignment of priorities also forced Detailed Design personnel to regularly move from one project to another in attempts to coordinate their priorities with those of management. Problems in the coordination of development resources can prevent improvements to development project performance which were intended by changes to the process structure.

1.3 The Problem

Static features and impacts of projects have been extensively researched and applied to project management practice (e.g. Barrie and Paulson, 1984; Moder et al., 1983; Halpin and Woodhead, 1980). In contrast, project managers do not effectively understand or utilize the dynamic features of development project structures (Cooper, 1994, 1993a,b,c, 1980; Cooper and Mullen, 1993; Sterman, 1992; Reichelt, 1990; Brooks, 1978). These dynamic features include feedback systems, time delays, and nonlinear cause-effect relationships among project components. These features combine to cause project systems to behave in complex ways which are difficult to understand, predict, and manage.

A simple example demonstrates the potential effects of feedback, time delays, and nonlinear relationships in project structures. Consider a project in which the expected completion date exceeds the deadline, creating a schedule gap. A common managerial response is to increase headcount (number of designers or crews) to increase output, move up the completion date and thereby reduce the schedule gap. This simple feedback structure can be described with the causal loop diagram (Goodman, 1988, Richardson and Pugh, 1981) shown in Figure 1-1. In casual loop diagrams casual links (arrows) are labeled as those which cause the variable at the arrowhead to move in the same (+) or opposite (-) direction as the variable at the arrow's tail, when other factors are held constant. Feedback loops are labeled as balancing (B) if variable values tend to be goal-seeking over repeated passes around the loop or reinforcing (R) if repeated passes accelerate movement in a single direction (Richardson, 1986; Richardson and Pugh, 1981).[1]

[1] A more rigorous definition of causal link and causal loop polarity is available in Richardson (1995).

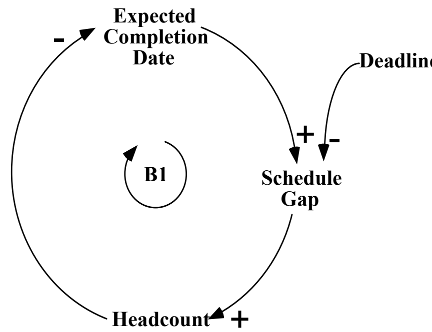

Figure 1-1: A Development Project Feedback Structure

The feedback structure in Figure 1-1 describes how the project condition (the size of the schedule gap) influences the managerial response to the system (change in headcount), which in turn effects the condition of the system (reduced schedule gap). In isolation the feedback structure in Figure 1-1 would restrain the project's schedule gap. But the feedback inherent in complex systems such as development projects often has many unintended side effects. For example Thomas and Napolitan (1994) identified fourteen secondary impacts of changes in construction development projects caused by three primary impacts (increased costs, schedule delays, and rework). Those fourteen secondary impacts are:

- Decreased worker productivity
- Lowered design team morale and productivity
- Relocation of labor
- Increased planning, coordination, and rescheduling activities
- Possible out-of-sequence work
- Demobilization, remobilization
- Overtime (fatigue) due to acceleration
- Crowding due to acceleration
- Possible seasonal/weather related impacts due to delays
- Increased effort to price out and negotiate the changes
- Learning curve associated with a change
- Inadequate coordination of changes
- Additional value engineering due to increased costs
- Possible litigation

An unintended side effect of increased time required to coordinate larger headcounts can be described with the reinforcing causal loop shown in Figure 1-2.

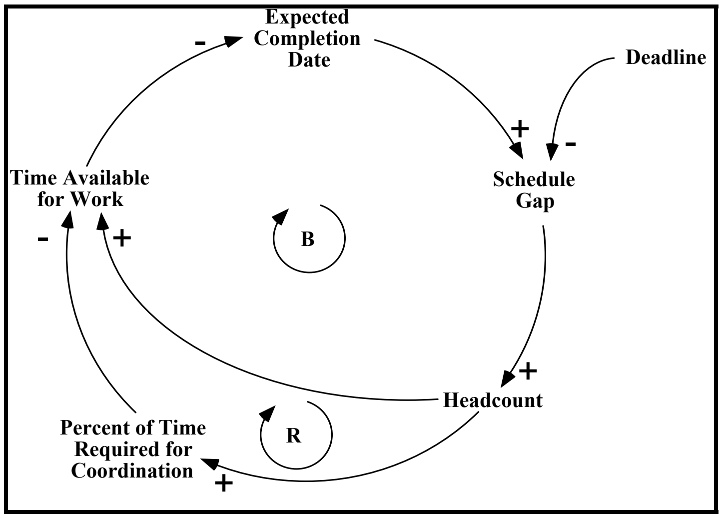

Figure 1-2: An Unintended Side Effect of a Project Management Policy

The unintended side effect shown with the reinforcing loop in Figure 1-2 counteracts the intended impact of the balancing loop. This is because some of the increased headcount is used to address the increased coordination need instead of increasing output. If the unintended side effect is larger than the intended effect it can extend the Expected Completion Date, increasing the Schedule Gap. This could occur immediately after implementation of the increased headcount policy. The relative strength of the balancing and reinforcing loops at any given time determines whether the Schedule Gap is increasing or decreasing. Which feedback loop dominates the system behavior is strongly influenced by another characteristic of dynamic systems, time delays. For example, a delay in the direct influence of Headcount on Expected Completion Date can cause the reinforcing loop to dominate soon after the headcount increase and the balancing loop to dominate later. Shifts of dominance among the feedback loops in a project structure cause project behavior to oscillate and can magnify impacts (Diehl and Sterman, 1995; Richardson, 1995; Forrester, 1961).

Nonlinear relationships among components is a third important characteristic of dynamic systems. An exponential relationship between Headcount and Percent of Time Required for Coordination is shown in Figure 1-3.

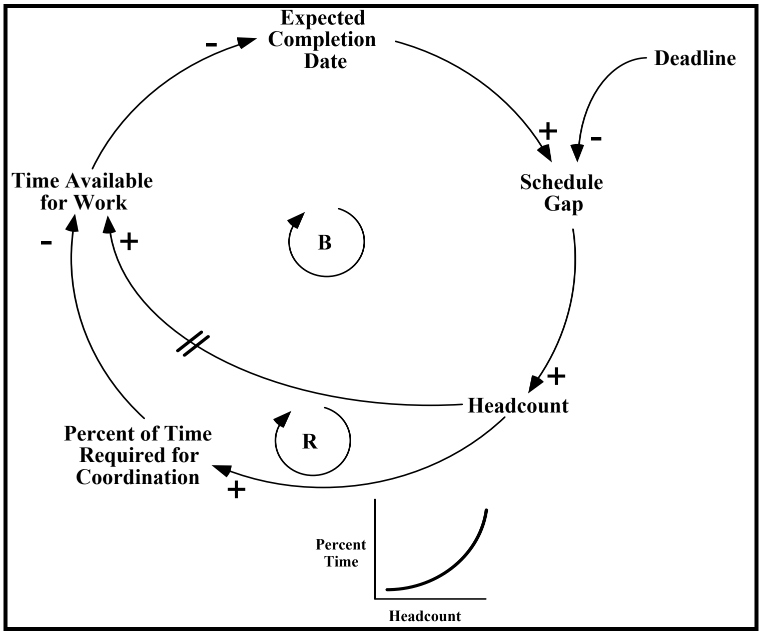

Figure 1-3: A Delay and A Nonlinear Relationship in a Project System

Nonlinear relationships make systems difficult to predict and manage by causing the system to respond differently to the same managerial action depending upon the system's current condition. For example, an increase in Headcount by 10% would generate a very small increase in Percent of Time Required for Coordination if the Headcount was small (left side of the Headcount versus Percent Time curse). But the same 10% increase in Headcount would generate a large increase in the Time Required for Coordination if the Headcount was high (right side of the Headcount versus Percent Time curve).

When project structures are described with causal loop diagrams management policies can be viewed as plans which attempt to alter the strength of causal link relationships between variables or create or delete feedback mechanisms represented by loops. In this way management policies can influence the relative dominance of different feedback loops. For example, a project manager may quickly add more people to a project when it gets behind schedule to increase the influence of the balancing loop. If the manager recognizes the potential loss of net productivity due to more time being needed to coordinate the work new technology which facilitates coordination may be introduced. This new technology is intended to weaken the relationship depicted by the arrow between Headcount and Percent Time Required for Coordination and thereby weaken the reinforcing loop which slows progress.

The combination of feedback, time delays, and nonlinear relationships in project structures have been shown to reduce performance and cause them to be very difficult to manage in the construction industry (Thomas and Napolitan, 1994; Reichelt, 1990; Cooper, 1981). The dynamic nature of project behavior precludes the generation of a single set of decision rules which are robust in the face of all possible project conditions. Project managers must use their understanding of project systems to adjust management policies such as those for coordination to specific project circumstances and the evolution of project behavior. This requires that development managers include dynamic features in their project mental models. But the mental models used to describe, explain, and predict projects do not generally include the dynamic features. Both complexity and dynamic features of projects are poorly understood by managers (Diehl and Sterman, 1995; Sterman, 1994; Paich and Sterman, 1993; Rechtin, 1991). The resulting inadequate project mental models prevent the development of decision heuristics which incorporate dynamic features into project management decisions. This deficit in decision heuristics therefore constrains project performance.

The underlying problem addressed by this research is the failure of project managers to fully recognize and utilize the dynamic features of projects which often drive project performance. Managers cannot effectively manage projects without understanding the impacts of dynamic features. The understanding and use of project dynamics which are currently used remains trapped in the intuition of experienced managers. An improved understanding of project dynamics is a first step in improving project mental models, decision heuristics, and thereby project performance. This research seeks to improve that understanding by increasing our knowledge of how product development process and coordination policy impact project performance. Developing a tool for an improved understanding of these impacts is the focus of this work. Therefore the research question is "**How does development project structure impact project performance?**" This question will be investigated through the building and validation of a dynamic simulation model of a development project and the use of that model to investigate a coordination policy for improved project performance.

1.4 Research Approach

The purpose of this research is to increase the knowledge and understanding of development projects. This improved understanding can act as the basis for improved project mental models, management heuristics and decisions, and project performance. While no single approach or model can provide a complete understanding of development projects, this thesis will contribute by identifying feedback relationships and other dynamic features which significantly impact project performance and by evaluating the nature of those impacts. This will be done by integrating existing but previously separate project structures into a single model and by expanding and testing previously unavailable project structures which have potentially large impacts on performance. The model is then applied to the investigation of a significant project management issue, coordination.

This thesis uses dynamic computer simulation to model and investigate the impact of development processes and coordination policies on project performance. A computer simulation model provides several advantages. First, the many and various project parameters and relationships can be modeled more comprehensively with the flexible representation available than with manual modeling methods. Second, assumptions are made explicit and unambiguous by their representation as formal equations. Third, consequences of assumptions and policies over time can be revealed through the simulation under safe experimental conditions. Finally, the model's reflection of actual project structures provides an effective means of communicating research work and results.

This research focuses on the development of a specific group of products, tangible durable products which evolve through a series of steps through the efforts of several specialists. This group includes many development processes in many industries. A generic set of activity names for the process being studied could include: 1) identification of need, 2) conceptualization, 3) product definition, 4) design, 5) testing, and 6) ramp-up to operations. The names and levels of detail which describe those steps vary widely among industries. For example one semiconductor development process uses the terms Market Study, Product Definition, Design, Pilot Product Solution (prototype testing), and Pilot Product Testing (manufacturing process testing). The relative importance of the different activities within the entire process can also vary widely. For example in the semiconductor industry ramping up to steady state production can take only a few weeks out of years of total development and is relatively inexpensive. In contrast the same activity in the real estate and construction industries is called construction and often takes as long as all other activities combined and costs many multiples of all other project costs. Despite these differences the model described herein can reflect the processes of many industries including manufacturing, real estate and construction, software, book publishing and feature film making.

The system dynamics methodology (Forrester, 1961) for modeling complex systems has been adopted. System dynamics describes cause and effect relationships with stocks, flows, and feedback loops. Stocks and flows are used to model the flow of work and resources through a project. Information feedback loops are used to model decisions and project management policies. Actual, desired and perceived conditions are explicitly and separately modeled. Time delays such as between the need for a development activity and the availability of labor to perform the activity are explicitly identified, as are nonlinear relationships. The methodology provides the means of describing the dynamic structures of development projects and therefore is an excellent foundation for this research.

1.5 Summary

The successful performance of product development projects is critical to competitiveness in many industries. Recent market and technology changes have increased the importance and difficulty of improving project performance. Although understanding the impacts of the dynamic aspects of development projects is increasingly important for improvement, these features are typically unrecognized, ignored or used inappropriately. An improved understanding of dynamic project features is needed to improve project mental models, decision heuristics, and thereby performance. This research contributes to this understanding by building and validating a system dynamics model of a development project and applying it to the investigation of coordination policies.