FALLACIES OF FAST TRACK TACTICS: IMPLICATIONS FOR ORGANIZATION THEORY AND PROJECT MANAGEMENT

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Timothy N. Carroll
College of Management, Georgia Institute of Technology
tim.carroll@mgt.gatech.edu

Richard M. Burton
Fuqua School of Business, Duke University
rich.burton@duke.edu

Raymond E. Levitt
School of Engineering, Stanford University
ray.levitt@stanford.edu

Arto Kiviniemi
School of Engineering, Stanford University
arto.kiviniemi@vtt.fi

Abstract

Accelerating or "fast tracking" projects hold the promise of faster project completion without a reduction in quality. Three common approaches to fast tracking involve changing sequential tasks to parallel tasks, adding more personnel of varying skill levels, and decentralizing decision making. However, each of these tactics for accelerating projects places significant additional information processing demands on managers. Extant organization theory does not explicitly consider the limits to these approaches – the points at which the potential schedule benefits of fast tracking are overwhelmed by the added information processing costs they create. We consider this issue by building computational models based on real-life project teams and varying these "baseline" models to consider the effect of each tactic. For each, the fallacy is that each of the tactics is generally effective; the limitation is that it depends upon the situation; and the refinement we add is that we explicate the limits of each strategy.

(Key words: organization design, organization structure, concurrent engineering, work processes, decentralization)

INTRODUCTION

"Time to market" pressures challenge managers to complete projects in less time, but without compromising project quality. For example, for a new product introduction the time to market has important strategic implications for competitive positioning and the company's revenue stream. Some examples help to illustrate its importance.

- ❖ For products like high-end microprocessors, the value of early market revenue can be as high as $1 million per hour, 7x24, with gross margins of around 50%. And market windows can be as short as three months, until a competitor—or the manufacturer itself—introduces an even faster microprocessor, so that prices need to be cut by 30% or more, eliminating most of the high, early gross margin.

- ❖ For an offshore oil platform in the North Sea, the "weather window" for installing the platform during a given summer is typically just a few weeks. Miss that window, and a year's revenue from the platform—hundreds of millions of dollars—is forfeited!

- ❖ Being first to market in consumer products often confers a different kind of advantage. Aside from early market revenue, successful buyer experience with a novel product—such as the first fluoridated toothpaste (Procter & Gamble), or the first functional wireless handheld PDA (RIM)—allows the producer to capture precious market share that can persist for years.

Faced with these overwhelming benefits of reduced time to market, managers often choose to employ "fast track" project designs. The term "fast track" actually applies to both the goal (dramatically reducing the time to complete a project) as well as the means to accomplish the goal. Simply, the challenge is to reduce project time without reducing quality. We examine three fast track tactics that are both used in practice and have theoretical underpinnings. The three fast-track managerial tactics or approaches:

- ❖ change some sequential tasks into parallel tasks that are performed concurrently;

- ❖ add more workers to the project (which tends to raise the span of control for middle managers); and/or

- ❖ change the decision making structure to greater delegation or decentralization.

We generally assume each of these approaches will reduce the time to completion and maintain or improve its quality. More formally, organization theory has examined these issues in terms of:

- ❖ interdependency and implications for organizational design,
- ❖ the effect of additional resources on organizational efficiency, and
- ❖ the advisability of greater decentralization.

In this paper, we model a real world project team operating under tight schedule constraints, then "virtually" examine the effect of implementing these three managerial strategies on project duration and project quality using an agent based computational model, SimVision®. We explore the limit of each managerial option alone, and in combination with others, to understand better the challenges in fast tracking projects. We find that these tactics have important practical limitations in their applicability to real projects. Further, the underlying organizational design theory needs to be refined and these limitations should be incorporated into the theoretical propositions for organizational design.

We model the project in SimVision® as an information processing organization where managers and worker agents perform tasks or work activities, communicate among themselves to handle exceptions, and coordinate the tasks in real time. SimVision® models both project tasks and management structure; it is an agent based information processing model of the project organization with which we can run systematic "virtual experiments" to examine the effects of managerial choices on performance. Each fast track tactic affects information processing directly, and thus performance indirectly.

- ❖ First, changing sequential tasks to parallel tasks makes the coordination of the tasks more complicated. If the parallel tasks are interdependent, this will introduce reciprocal interdependencies where previously there were sequential interdependencies. The latter are much easier to manage and require much less communication and coordination. Higher levels of reciprocal interdependency require more face-to-face coordination or "mutual adjustment" (Thompson 1967) between workers performing interdependent tasks – an additional information processing load for already stretched workers and managers. This

hidden coordination cost is ignored or at least underestimated by many proponents of "concurrent engineering".

❖ Second, increasing staffing levels increases the manager's workload as there are more individuals to manage, i.e., the span of control increases. New workers will also encounter more frequent "exceptions"—situations in which they lack some of the information or knowledge required to complete their task. Hence, incremental workers are likely to require even more supervision per person in the startup phase on the project than experienced workers on the project. These additional exceptions need to be handled by more experienced colleagues or supervisors, thereby increasing their workloads (Galbraith 1974). In some cases, adding additional workers actually slows down the overall progress of a project like a complex software development effort (Brooks 1974). When the workers are performing simultaneous (vs. sequential) tasks the exception handling rate further increases for managers, even if all workers are equally skilled—and, as pointed out above, they are probably not!

❖ Finally, the project manager can delegate decisions to lower level managers or workers on the project. Decisions can be made more quickly on local information; but local managers or workers may lack information about the global effects of their decisions. That is, there can be a quality loss due to local optimization. This can increase the number of global exceptions to be handled later in then project and further result in project quality problems.

The result of each managerial option is that the "hidden work" associated with coordination and supervision rises in fast track projects. As discussed in Levitt et al (1994), individuals with backlog or information processing overload tend to focus on their own work and underemphasize coordination. Coordination failures will then frequently occur, leading to increased numbers of downstream errors, more rework to address those changes or errors that are detected, and increased errors which go uncorrected, all which can lead to decreased subsystem and system-level quality, and missed deadlines.

It seems clear that high managerial information processing loads through increased task interdependency, increased worker numbers and changes in delegation or decentralization can lead to

higher coordination costs and more likely coordination failures, that can outweigh the benefits of schedule compression. Our intent in this paper is to understand more precisely the tradeoffs associated with fast track work processes and organization designs, and to find appropriate levels of task interdependency, task overlap, additional workers, span of control and decentralization to optimize project performance.

These issues are addressed by developing a number of computational models tested as controlled variables of a baseline model that is based on a set of field studies.[1] These models vary the organization design by focusing on the effects of task structure (sequential versus parallel), personnel (adding additional people, increasing spans of control), and decision making (increasing decentralization) as fast track designs are progressively implemented. We begin by reviewing the relevant literature from organization theory and project management. Then, we describe the SimVision® model and our experimental design. Next, we report results for the fast track strategies both in isolation and in combination. Finally, we discuss the results and the implications for organization theory and for managerial practice.

The main contribution of this paper is a better understanding of the fallacies of fast track tactics that project managers use and the theoretical implications for refinements in organizational design propositions. More specifically, we develop:

- ❖ the fallacies of fast track tactics for concurrent tasks, and the theoretical implications and refinement of the concepts of sequential and reciprocal interdependencies;

- ❖ the fallacy that additional resources are helpful, and the role of skill level and tasks; and

- ❖ the implications of delegating decisions in a project and the qualification of the design tactic of decentralization for efficiency.

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[1] The research involved models based on two field study sites – the first an industrial gas company R&D team and the second a medical inventory management project at an academic medical center. For brevity's sake, we report only the results of the first project, as the results are qualitatively similar.

For each, the fallacy is that the tactics are general, the limitation is that it depends upon the situation, and the refinement is that we explicate where the limitations obtain.

INTERDEPENDENCY OF TASKS

The first and most common approach to fast track designs involves changing sequential tasks to parallel tasks, which increases the level of interdependency between tasks . Although interdependency has been and remains one of the central concepts in organization theory, the term "interdependency" covers a wide range of concepts (Staudenmayer 1997). Theorists view interdependency as inherent in the nature of the technology employed (Thompson 1967), as a consequence of organizational design (Burton and Obel 1980; Wageman 1995), as a result of external pressures (Ancona and Caldwell 1992; Gresov 1989), or as the outcome of individual's perceptions and process of "sense making" (Weick 1990). It is defined as a contingent relationship between tasks (Thompson 1967), an attribute of a relationship within a particular context (Kelley and Thibault 1978), and in terms of control over resources (Pfeffer and Salancik 1978).

Here, our framework follows Thompson (1967). He defined interdependency as "the extent to which a task requires organizational units to engage in work flow exchanges of products, information, and/or resources, and where actions in one unit affect the actions and work outcomes in another unit." In short, interdependency is viewed as a varying degree of contingency relations among tasks that is inherent in the nature of the technology.

Thompson further identified three types of interdependency and discussed methods for addressing each type. *Pooled* interdependencies occur when "each part renders a discrete contribution to the whole and each is supported by the whole although the parts do not interact in any direct way." Thus, the individual tasks have no contingency with each other, only on the project level (such as for resources). The way to manage pooled interdependencies is through standardization, rules, and procedures.

A second type of contingency is *sequential* interdependency. This type of interdependency exists when the output of one task is the input for another. Thus, there is an asymmetrical relationship between the tasks. Sequential interdependencies are often managed via plans, schedules, and feedback.

The last type of interdependency, *reciprocal*, is the most difficult to manage. In this case the output of one task is input for another, and vice versa. The actors responsible for the reciprocally interdependent tasks must effect coordination through the costly process of face-to-face "mutual adjustment." Thus, reciprocal interdependency is different in both kind (the task structure) and degree (the information processing load) from the other types.

We focus on reciprocal interdependencies that result from the implementation of fast track organization designs, i.e., changing sequential to reciprocal interdependency. We extend and refine Thompson's interdependencies in several important ways. First, we find his definition of reciprocal interdependencies ambiguous and tautological—i.e., it is the kind of interdependency whose coordination requires mutual adjustment. We prefer to view reciprocal interdependencies as existing between pairs of tasks with "negatively interacting subgoals", as stated in Thomsen et al. (1998). Each task has several subgoals that actors attempt to maximize or satisfice. When optimizing one or more of a task's subgoals comes at the expense of reduced performance for one or more subgoals of another task, a reciprocal interdependency exists between the two tasks. This view of reciprocal interdependency as arising from negative interaction between the subgoals of pairs of tasks is unambiguous, and makes it clear why negotiation is needed between the actors responsible for the two tasks—i.e., one or more subgoals of the two tasks must be negotiated through a process of "mutual adjustment."

Second, rather than viewing task interdependencies as fixed, Levitt (2004) proposes that the nature of task interdependencies arises from task attributes, but is mediated by management decisions regarding team organization and workflow. Two examples illustrate this mediating effect of managerial decisions on the nature of task interdependency.

❖ Introducing a shared resource that is required to perform two tasks with only pooled interdependency changes the interdependency to sequential. Task A must now be performed before Task B or conversely. For example, choosing components large enough to require lifting with a gantry crane in a factory means that they cannot both be installed simultaneously. One must wait for the other to be completed. This requires hierarchical

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planning to coordinate—a more costly form of coordination than the rules and standards that could be used to coordinate the tasks when they only had pooled interdependency. Note that fast track projects typically require human resources to be shared across tasks, introducing new sequential dependencies between the tasks for which some team members must now allocate their time.

❖ Moreover, sequential interdependency can become reciprocal interdependency (and vice versa) through changes in the design of workflow. If a manager schedules two reciprocally interdependent tasks (i.e., tasks with negatively interacting subgoals) so that they will be executed in sequence, she is implicitly prioritizing the subgoals of the first task over those of the second. Upon completion of the first task, its outcome—with locally suboptimized subgoals—will be passed to the second task as input. The individual responsible for the second task can now only attempt to optimize its tasks' subgoals conditional upon the decisions made in the first task. Thus, from a coordination standpoint, the interdependency has devolved to a sequential, rather than reciprocal relationship. When a manager subsequently attempts to take time out of the schedule for this project by overlapping the execution of such quasi-sequentially interdependent tasks, the implicit prioritization is eliminated and the underlying reciprocal interdependency is reactivated. The more complex task interdependency that this causes, and the exponentially higher coordination load thereby imposed on the organization to perform large amounts of mutual adjustment, is often overlooked by managers attempting to fast track projects—sometimes with disastrous results.

This leads to the first tactic or proposition:

Tactic 1: Changing sequential tasks to parallel tasks (thereby increasing reciprocal interdependencies) will lower the project completion time with no impact on project quality.

The suboptimal decisions that result from making reciprocally interdependent decisions sequentially interdependent provides the impetus for much of the research and writing on "concurrent engineering" as a way to increase global optimality of decisions by requiring negotiation of, for example, design and

manufacturing tasks' subgoals. However, the proponents of concurrent engineering have by and large ignored the exponentially increased coordination costs that this approach imposes on the organization, if taken too far. But managing the reciprocal interdependencies via mutual adjustment is only part of the story. Workers performing tasks of all kinds, whether or not they have interdependencies with other tasks, will periodically encounter "exceptions" (Galbraith 1974). These exceptions generate another kind of information processing requirement for the organization – the classic hierarchical exception handling described in the Galbraith model. Thus, when any set of tasks performed by the subordinates of a given manager becomes more parallel, the rate at which exceptions are generated for that manager increases, potentially overloading the manager with exception handling requests.

When both of these effects occur simultaneously—more concurrency of tasks and more reciprocal interdependency— the information processing load rises rapidly. Each worker has, on average, more interdependent tasks that require coordination with other workers. Managers now receive exceptions from workers reporting to them at a higher rate (because more tasks are going on at the same time). This is true even when the tasks being performed by subordinates have only pooled interdependency with one another. When the resolution of an exception requires a worker performing a reciprocally interdependent parallel task to make a change, the worker responsible for the task at the other end of the reciprocal interdependency link will likely need to make a compensating change, potentially generating new exceptions for his manager, and so on. Moreover, as described above, the introduction of incremental workers with lower average skill levels, and the resulting increased spans of control for managers, doubly compounds these information processing overloads on the organization.

These combined effects trigger a spiral of coordination, exceptions, rework, compensatory coordination, new exceptions, and so on, when managers attempt to shorten schedules by introducing more parallelism among previously sequential, reciprocally interdependent tasks.

Interdependencies then are part technology-determined, and in part the choice of the project manager deciding how to subdivide and sequence tasks, and how to assign resources. The process of structuring workflow and allocating subtasks modifies the interdependencies that exist based on the

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technology employed (Wageman 1995). The outcome of these organization design decisions determines the ultimate degree of interdependency that exists—and must be coordinated—between tasks.

The type of interdependency between tasks affects the amount and type of information processing needed to effect coordination between interdependent tasks. In the information processing view (Galbraith 1974; March and Simon 1958; Simon 1976), organizations must process information as part of task completion. The amount of information to be processed depends on several factors, such as the complexity and uncertainty of the tasks. As sequential tasks are changed to parallel tasks, we have shown how the amount and complexity of required coordination increases (Burton and Obel 1980). The higher the degree of coordination necessary to perform tasks, the higher the information processing demands will be on the individuals in the organization. The challenge is that there are limits (cognitive, attentional, organizational) to individuals' information processing capacity. When the information processing demand exceeds capacity for any individual or group, coordination will be underemphasized.

Organization theory does not explicitly address the point at which the benefits of integration are outweighed by the costs of coordination. Galbraith's (1974) information processing view of organizations provides qualitative insights into the tradeoffs that exist, but only operationalizing and quantifying the variables in his framework would allow managers to resolve the qualitative ambiguity that arises from countervailing effects in making this tradeoff. Our modeling approach allows us to explicitly demonstrate the point at which the information processing costs outweigh the benefits, which shows the limits of this first approach to fast track project designs.

EFFECT OF ADDITIONAL PERSONNEL

The second approach to fast track design assigns additional personnel to the tasks most likely to delay the project. Again, our focus is on the effects of information processing on the project team as team size increases, ignoring other potentially negative effects such as an increase in social loafing (Latane et al. 1979) and a decrease in group satisfaction (Yetton and Bottger 1983). From an information processing perspective, increasing the number of personnel on a project has a two-sided effect. First, there are more

individuals to perform the tasks or do the work. Second, there are now more individuals to manage which takes time and the effort of the management. That is, there are pluses and minuses for the project duration and the project quality.

The promise of additional personnel is that they will decrease project completion time by assigning them to the tasks on the critical path which are most likely to cause bottlenecks. Thus,

> *Tactic 2: Assigning additional personnel to critical tasks will lower the project completion time with no impact on project quality.*

However, there are reasons to question this approach as well. In Brooks' (1974) classic essay on the "mythical man month", he analyzes a real situation for software engineering and argues that adding personnel to a behind-schedule project can quickly overwhelm management such that the project suffers further both in duration and quality. In his experience, the negative effect is realized with only a few new individuals on a project. The implications are clear that simply adding few more "bodies" to a project can be harmful. It seems reasonable to expect that the severity of this effect depends upon the skill of the individuals and how much management time is required for the new individuals.

The skill of the individuals can have a complicated effect. Elliot Jaques in numerous writings and based upon his experience and observation suggests that well motivated and highly trained individuals take less time to manage; and thus, the span of control can be wider for these situations (c.f. Jaques 1998). However, Burton and Obel (2003), building upon Kowtha's (1997) empirical work, indicate that higher skilled professionals have greater information processing demands, thus suggesting that higher skill individuals take more time to manage. The resolution depends upon the particular context and project task requirements. Specifically, the extent to which adding additional workers will accelerate *vs.* delay a project depends on the fit between their skills and experience and the requirements of the task. Adding high-skilled and appropriately experienced workers can accelerate schedule without delaying quality. Adding workers who lack either the requisite skills or experience with the kind of project under development can actually delay the project and lower its quality.

Earlier, Mackenzie (1974) considered the span of control in terms of the information processing and time demands of the manager. He summarizes the time categories as: internal calculations, non-subordinate interactions, and subordinate interaction in the context of slack time and manager work norms. There is a balancing of the manager's time demands and the available time, i.e., an information processing model of managerial work. As such, the managerial demands are specific to the task requirements (the project task in this case) and thus, it is not possible to state a definite number for the maximum span of control.

In these studies, it is clear that management can become overloaded by a combination of direct work (performing their own tasks) and indirect work (coordination and supervision) to an extent that organizational projects will suffer. Our expectation is that the relationship between adding personnel to a project and project duration is nonlinear, such that there are initial benefits to adding personnel until the point where the costs of managing additional personnel outweigh the benefits. After this point the project duration increases, consistent with the mythical man month argument.

DELEGATION AND DECENTRALIZATION

The third approach to fast tracking delegates or decentralizes decision making. This frees up managers' time to work on other activities (Galbraith 1974) and allows decisions to be made in a more timely fashion as it is not necessary to fit into the managers' schedule or the queue of things to be done. So, there are two effects: managers have time to perform other activities, and decisions are likely to be made more quickly. This decreased managerial information processing load leads to:

> *Tactic 3: Increased decentralization of decision making will lower the project completion*
> *time with no impact on project quality.*

But decentralization has its downside as well. Decisions made by lower level actors are more likely to consider only the local phenomenon and not the impact on the project as a whole. Thus, local, specialized actors have suboptimal preferences (Lawrence and Lorsch 1967), which can have high costs in terms of project duration and project quality. This downside may be mitigated by a strong shared organizational

culture which embodies global preferences and tradeoffs to guide workers in making high-quality, decentralized decisions (Porras and Collins 1994).

Decentralization also requires more coordination for interdependent activities that would otherwise require complicated rules. Further, although decentralization lessons the burden on managers by removing some of their potential decision making requirements, exceptions to the usual processes are less likely to be recognized and handled appropriately. These exceptions, in turn, are a product of the uncertainty of the environment and/or the project task which require decisions for which rules are not evident, i.e., exceptions or novel situations (March and Simon 1958). Thus, managers may in fact face an increased information processing load due to more exceptions generated by their subordinates.

It is very difficult to decentralize decision making and maintain the required coordination. Galbraith argued that decentralization in projects would lead to greater efficiency and shorten the project duration (Galbraith 1974). Many authors have made similar arguments (Thompson 1967). Levitt, et al. (1994) have also observed this performance outcome. Kim and Burton (2002) showed in a computational experiment using SimVision® that the project duration was decreased with greater decentralization, but that the project quality could suffer as the coordination of project tasks is not realized. Project quality deterioration is a direct result. Thus, there is a tradeoff between duration and quality objectives, where greater decentralization can lead to shorter duration but with lower project quality.

Galbraith (1995) argues that a number of environmental changes (shorter product cycle times, globalization, pressures for innovation and organizational learning) require the design and implementation of "lateral organizations", characterized by increased horizontal coordination and decentralization. He notes that the increased emphasis on lateral relations should permit the organization to make higher quality decisions more rapidly, but only at the cost of the additional time required to coordinate and integrate across functions (Galbraith 1974).

RESEARCH DESIGN

Our goal is to understand the effect on performance of the three managerial fast track tactics with 1) the move to greater reciprocal interdependencies 2) the increase in personnel and 3) decentralization in decision making. The method we use is as follows. We establish a real world, "as is" baseline model of a project task and organization configuration developed from our field study site. We then explore variants of this baseline model by modeling and simulating the three alternative managerial tactics, i.e., organization designs different in these three ways from those chosen by the managers and employees in our field study cases. In particular, we manipulate the baseline project organization designs to impose: 1) a greater or lesser degree of parallelism, with attendant increased reciprocal interdependencies, 2) more personnel, and 3) delegation of decision making. Finally, we continue the virtual experiments by combining the three approaches, to see whether the interaction effects modify the previous results.

<center>(Insert Figure 1 around here)</center>

Research Site: Industrial Research and Development Laboratory Team

The field study site (see footnote #1) was a Research and Development (R&D) team at an industrial gas company in the Northeast United States. The R&D project team developed a next-generation heat treatment system. The system is built around a specialty oven that bakes metal parts using particular gases at a prescribed temperature and duration to give the metals specific desired properties of strength, ductility, etc. One of the largest clients is the automotive industry, which uses the system to produce catalytic converters, among other parts. The R&D team's goal was to develop a product that gave their customers an increase in treated materials throughput of at least twenty percent. The team members were all from the same company except for one individual who worked for a subcontractor. Five individuals were engineers (including the project manager and subcontractor); the last team member was an attorney.

There were three major workflows in the project. The first was to find a test site for the system. This involved identifying potential customers, then negotiating and signing agreements. The second workflow was to design the oven. Here, the first design choice was which gas (methane or carbon) to use.

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After the gas type was chosen, the oven was designed, parts ordered, and the system built and tested. This workflow had potential interdependencies with the first workflow (signing agreements), as the type of customer application affected the type of technology (e.g., gas type) employed. The last workflow stream was to design and build a control system for the oven. As with the oven design workflow, a basic technology was chosen up front (such as infrared or laser), then designed, built, and tested. The project finished when the heat treatment system produced acceptable parts at the customer field site.

The baseline project organization design included several reciprocal interdependencies. For example, the type of customer chosen for the test site affected the type of oven design, and vice versa. This reciprocal interdependency had to be managed by mutual adjustment. In addition, the project manager could structure the work in such a way that there were additional reciprocal interdependencies. For example, in the baseline model the engineers built a test model in the lab and ran it for a period of time to work out early problems. Then they installed the system at the customer site and further assessed the functionality and performance. Alternatively, it would have been possible to run the lab tests and beta site tests in parallel, rather than in sequence. It would likely result in more problems in the field test, but it also had the possibility of reducing the project completion time.

The Virtual Design Team and the SimVision® Software Platform

The software platform used in this research is the SimVision® simulation model first developed by the Virtual Design Team researchers at Stanford University's Center for Integrated Facility Engineering (Levitt et al. 1994) and later refined by Vité Corporation. This software program allows an organizational designer or researcher to specify the tasks, actors, activities, and linkages between them in order to simulate project team performance. SimVision® is based on the information processing theories of Galbraith (1974), March (March 1988; March and Simon 1958), and Simon (1976). It views the organization as an information processing and communication system, comprised of (boundedly rational) limited information processors (either individuals or groups) who strive to achieve a specific set of tasks. The researcher or manager may specify the decision-making characteristics of the organization (such as

high, medium or low levels of centralization and formalization), the number, skill set, and experience

levels of actors (or encapsulated teams of actors), and the process workflow (including dependencies

between actors or activities). Higher complexity tasks require the actors to cope with increased

information processing demands, given finite time and attention. The accuracy of the predictions made by

VDT and SimVision® have been validated on hundreds of projects in industries ranging from

construction, capital equipment and aerospace through consumer products, semiconductors and software

development (Levitt et al. 1994).

Method

We build simulation models based on real-world project teams, capturing the interdependencies and

coordination of teams aiming to reduce project completion time while maintaining acceptable quality and

cost levels. This has an advantage over sparse, idealized "intellective" models by capturing real, time-

bound projects with different coordination needs at different times (Bailetti et al. 1998). Research that

focuses only on ongoing operations and not on time-bound projects miss the important temporal

dimensions of the organization design problem (Adler 1995).

We created a baseline simulation model (again using SimVision®) that captured the way that the

project teams currently operate, using interviews with project team members to inform and validate the

model. Input variables in the model include identifying the actors, the activities or tasks that the actors

perform, the sequence of activity completion, and the communication links. The actors are individuals or

undifferentiated "subteams" of individuals performing the same tasks; activities are the tasks that the

actors perform. The total work volume for an activity includes both production work (i.e., design) and

coordination work (i.e., communication and decision making to carry out the design) volume. Based on

the interviews, production work volume of each activity and the sequences of activity completion (which

activity outputs are inputs for other activities) were set a priori. The coordination work volume emerges

from the communication patterns in the organization. These communication patterns are the result of

hierarchical supervision (reporting relationships), information exchange links and failure propagation

links. Two activities share an information exchange link when the activities are reciprocally interdependent, that is when the two activities must be coordinated through mutual adjustment. Tasks may require rework either because of an internal failure or a failure in a dependent task activity.

Semi-structured interviews provided the inputs to the initial model. Further interviews validated the SimVision® baseline model with several key contacts, including the project manager. The interviews also covered alternative ways that the team members could structure their work for more efficiency (same performance goals, quicker time frame). This was done in order to generate alternative organization designs that would vary the degree of parallel activities.

Task Interdependency

Managers may choose to design projects that rely on more parallel rather than sequential tasks, creating more reciprocal interdependencies. To test the effect of increasing reciprocal interdependencies on the performance of the project, we created a number of alternative models to the baseline model. Using information gathered from the interviews, we generated around 35 alternative project organization designs with varying levels of reciprocal interdependency by changing sequential activities to parallel activities or vice versa. There were at least three different organization designs for each level of reciprocal interdependency. The scheduled project completion time for each model was known a priori, based on the workflow and task activity durations. Running the models gave more realistic predictors of project completion time that includes supervision and coordination effort. The output data include information on the level of indirect work (coordination, rework, and wait times) and quality. Process quality metrics include the ratio of unattended communication requests to overall communication requests and the ratio of (ignored + "quick fixed") vs. reworked exceptions to total exceptions.

In reality, there are limits to the degree of parallel tasks, and thus reciprocal interdependencies. Some tasks are linked in such a way that one causes, requires, or lags another (Darwiche et al. 1988). For instance, a roof cannot be installed without wall supports, which in turn require a foundation. In the field study simulations we limited the generation of parallel tasks to those that the managers deemed feasible.

In many cases the managers believed that some of the tasks should not be made parallel. One of the strengths of simulation modeling is that it enables the researcher to do "unreasonable" things. Thus, the level of interdependency was pushed beyond what the managers considered prudent in order to observe the effect on performance, as long as they were technically feasible.

Additional Personnel

The second fast track approach assigns additional personnel to backlogged (or potentially backlogged) actors. In the field study project team there are two project supervisors who report to the project manager. Both of these supervisors have high workloads, a combination of direct and supervisory tasks; they frequently get backlogged. Our second test is to assign personnel of various skill levels to them in order to alleviate their direct workload. Thus, beginning with the baseline model (the actual organization design employed by the project team) we added personnel (with high, medium, and low skill levels) to the major tasks performed by the supervisors. In SimVision® high-skill workers perform direct work faster and with fewer exceptions than the default-medium skill workers. Low-skill workers process work more slowly and with more frequent exceptions than medium-skill workers.

Decentralization

The third test looks at the effect of decentralizing decision making by increasing the propensity of actors in the simulation to handle exceptions themselves or to seek advice from first-level subteam leaders, rather than looking to senior project managers for help. The SimVision® model is based on ethnographic studies that calibrated the decision making of workers, first level managers (subteam leaders) and project managers about how to handle exceptions. It was found that managers are more conservative than subteam leaders, and subteam leaders are more conservative than individual workers or subteams in requiring that exceptions get reworked or "quick fixed", rather than being ignored.

With high centralization most exceptions are referred to project managers for decision making; with medium centralization, first level managers handle most exceptions; and with low centralization,

empowered workers make most of their own decisions about how to deal with exceptions. Thus an organization culture of high centralization will result in a larger fraction of exceptions being reworked, and an attendant higher level of process quality than one with a medium or low centralization.

The correlation between level of centralization and level of process quality breaks down when project managers or subteam leaders become backlogged with too many exceptions and take too long to issue decisions. In this case, the exceptions "time out" in their in-baskets, and the worker who encountered the exception makes a "delegation by default" decision, with lower average quality. When high-level managers in a project team become severely backlogged, the entire organization begins to operate in a "decentralized by default" mode, and quality risks can increase rapidly.

In this experiment, we simply varied the degree of centralization on the models previously generated to test the interaction of centralization with task interdependency and personnel issues.

RESULTS

Task Interdependency Results

Reciprocal interdependency arises when one or more subgoals of two tasks interact negatively with one another (see section 2), i.e. a solution that is better for one task is worse for the other (Thomsen et al. 1998). For example, there was a reciprocal interdependency between the lawyer identifying potential field study beta-testing sites and the engineers designing the heat treatment system on the industrial gas R&D team. Since attempts by the two parties to optimize without coordination will lead to a suboptimal or even unacceptable global solution, this type of interdependency requires that actors engage in face-to-face coordination or "mutual adjustment" (Thompson 1967) and attempt to negotiate a solution that makes the appropriate tradeoff between their interacting subgoals. This is costly in time and effort.

The primary benefit of less concurrency is a lower coordination cost, since the need for extensive negotiation regarding tradeoffs among reciprocally interdependent tasks is negated by scheduling one of them ahead of the other, implicitly prioritizing the subgoals of the preceding task. The decisions that affect the subgoals of the first task are already made before the second task begins, and all of the required

information transfer can be done instantaneously with the handoff of the task to the second actor. This is why any attempt to increase the level of parallelism of tasks with negatively interacting subgoals is likely to transform some sequential interdependencies back into reciprocal interdependencies.

The simulation results show that increasing the level of reciprocal interdependencies by making sequential tasks parallel initially decreases the project duration (see Figure 2), from an initial level of 669.3 to 471.9. However, when we introduce more concurrency, and the level of reciprocal interdependency increases further, the project duration rises at an increasing rate (to a high of 1265.4 at six reciprocal interdependencies). The error rate is measured both for the tasks themselves (functional errors) and by the likelihood that the components produced by the project will not be integrated at the end of the project, or that task integration will be incomplete based on rework and exception handling (project errors). Error rates over this span of reciprocal interdependencies are essentially unchanged. There were no significant changes in this measure of system integration as reciprocal interdependencies were added for this case.

Additional Personnel Results

In another attempt to reduce the duration of the baseline situation, we simulated the effect of adding personnel of varying skill. Similar to the u-curve effect above, the project duration initially decreases and then increases markedly, as shown in Figure 3. As suggested in Brooks (1974), the skill level of the additional personnel is quite important. Adding a few low skill personnel decreases the project duration slightly, but not as much as adding high skill personnel; adding low skill personnel beyond two leads to project duration increases. The effect is more pronounced for low skilled workers, but it even occurs for skilled personnel. That is, high skill personnel are indeed more productive as reflected in the project duration. In short, it is better to add high skill personnel than low skill; however, adding more than a few of either leads to longer project duration as the manager becomes overloaded with incremental supervision and coordination work.

For the project quality, adding personnel increases the error rate (thereby decreasing quality) monotonically, as reported in Table 2.   Thus, as additional personnel join the project team the amount of exception requests increases. Given finite managerial time and attention, a progressively greater proportion of these exception requests are ignored.

This effect alters when increasing reciprocal interdependencies and adding personnel in combination. At low levels of interdependency adding people monotonically reduces project duration. At high levels of reciprocal interdependency adding people monotonically increases project duration (Table 4). At moderate levels of reciprocal interdpendency project duration follows the u-shape curve reported above. For every level of reciprocal interdependency the error rates are essentially unchanged as additional personnel are assigned to the project. Alternatively, for any number of additional personnel error rates actually peak at moderate levels of reciprocal interdependency.

Decentralization Results

Decentralization may be expected to improve project completion time by reducing the information processing demand on the project managers. In fact, higher levels of centralization, in all cases, improved the results of our models. In isolation, this reduced the project duration by a small amount (from 621.4 for medium centralization and 612.8 for high centralization), as reported in Table 3 and shown in Figure 4. The result was more dramatic for the most decentralized models, which in fact never completed due to infinite errors and rework. Thus, there was a small benefit to centralization and large cost to decentralization in terms of completion time. These results were more pronounced when combined with the other manipulations.

The level of centralization does not affect the overall trend in project duration, but affects the magnitude of the changes. Thus, when centralization is at a moderate level (reported above), there is an inverted u-shape curve – duration is lowest when there are around two additional employees on the project team. If the centralization is low, the negative effects of additional people are visible earlier and more strongly than in an organization with high centralization, although this is contingent on the amount

of time the supervisor has to devote to the project. When the supervisor has the capacity to respond to exception handling requests, then the project performs best at higher levels of centralization. Results are worse for moderate levels of centralization and the modeled projects actually never finished at the lowest levels of centralization.

Similarly, the more centralized the project is the higher the quality is. This is because managers are more likely to handle an exception positively (i.e., to perform needed rework) than the front-line employees, an assumption of the model based on prior ethnographic research (Christiansen 1993; Cohen 1993). While this may not be true in all situations, such as customer service teams, it does hold true for the engineering-oriented tasks that are the focus of this paper.

These results are contingent upon the managerial time available, especially from the project manager. In our baseline models the project manager had sufficient time to attend to requests for exception handling and supervision, even when additional personnel and more interdependent tasks placed addition demands on him. When we relaxed this assumption by taking away some of the manager's slack time these results did not hold.

DISCUSSION AND CONCLUSION

This paper provides a more nuanced and robust view of the approaches to fast track project design. We explored the effect of the three major approaches to fast tracking – schedule compression, adding personnel, and decentralization. We have shown that the usual tactics for fast tracking are limited in their practical application. We have added precision to organizational theory notions of interdependency and for fast track project practices.

Our virtual experiments perturb empirically observed project organization and work process configurations to show that the intuitive tactics used by managers for concurrent engineering—i.e., increasing the level of parallel tasks and thereby increasing the level of reciprocal interdependency—only works in restricted cases. As reciprocal interdependencies increase, the information processing demands they generate can quickly overwhelm any direct benefits of schedule compression. Thompson's (1967)

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categorized interdependencies as pooled, sequential and reciprocal. Each has different implications for the information processing (Burton and Obel 1984) and the management of the project.

Thomsen et al. (1998) eliminated the ambiguity of reciprocal interdependency by defining it as "negatively interacting subgoals" which then create the need for mutual adjustment. In our studies, these managerial processes are modeled and the implications are made explicit. Moving tasks from sequential to parallel creates more complex coordination of tasks and adds time demands for the management. We found that making a very limited number of sequential tasks parallel can increase performance, but very quickly the added coordination demands overwhelm the advantages of the concurrency. The nonlinearity of the relationship of concurrency and performance adds precision to our understanding of interdependency beyond the simplistic intuition that increasing the number of parallel tasks or concurrency will decrease schedule, with no loss of quality.

The second tactic, in which managers add additional personnel to the critical tasks in a project to shorten project time seems intuitive and quite reasonable. Earlier, Brooks' (1974) "mythical man month" effect suggests that the opposite outcome is not only possible, but even likely. We confirm the mythical man month effect—adding more than one or two personnel adds to time demands and coordination load of management and can rapidly increase schedule, especially if the additional personnel are low skilled. In brief, low skilled personnel require significant management time and so make little net contribution to a project's progress. Additional personnel require managerial attention. A few additional personnel can be beneficial, but only a very few of the appropriate skill, who do not require much managerial attention. Otherwise, more can be less!

Decentralization or delegation of decision making is an intuitive tactic for the busy manager. Galbraith (1974) argued that decentralization would shorten project time and lead to greater efficiency; it leads to timely decision making under uncertainty. In our studies, we found contrary results that both project duration and project quality can suffer with greater decentralization. Greater decentralization means that lower level managers make decisions on local information, and thus are not able to coordinate their activities globally. This lack of coordination leads to more rework and diminishes the overall

quality of the project. Thus, the simple decentralization tactic is limited in its scope. For projects with high levels of reciprocal interdependency, decentralization leads to diminished performance. However, when tasks are not interdependent, decentralized decision making can enhance performance.

In sum, our results show both the promise and the peril of increased interdependency, additional personnel and decentralization in terms of information processing. The common theme is that each of these intuitively reasonable tactics increases the coordination demands and managerial time requirements – practical issues which have not been fully appreciated either in the theory or practice. Previous work often focused on a subset of these results. A number of innovation studies, for example, have also highlighted the importance of integration; scholars have argued that effective product development teams coordinate through frequent and intensive communication and feedback (Imai et al. 1985; Wheelwright and Clark 1992). Similarly, others conclude that successful projects transfer knowledge through the organization through a high degree of interaction between the R&D function and the other functions (Hansen 1999; Henderson and Cockburn 1994). An approach that relies on increased communication and coordination, as these studies advise, is less likely to be useful when the number of interdependencies increases, since higher levels of interaction and communication increase the information processing load on workers, and especially on managers. This increased coordination can result in higher quality, but the overall result will be negative if the premium placed on project duration (speed) or cost leads to backlogs for managers and resulting "delegation by default" decision making. Schedule compression, for example, only reduces the overall project duration (or holds the promise of doing so) when the tasks are located along the longest or "critical" path of sequential project tasks. But attempts to shorten the critical path directly by overlapping previously sequential tasks is problematic due to the increased information processing demands that this puts on actors who must accommodate each other through mutual adjustment.

We expand on previous work by elaborating the effects of three fast tracking approaches, both in isolation and in combination. However, previous work already provides some insights about managerial approaches to mitigating the information processing challenge. For example, Galbraith (1974) argues that

potential strategies for managing excessive information processing load involve either demand reduction (by creating autonomous, modular subprojects, and/or by adding slack resources to tasks) or increasing information processing and flow capacity (through investments in better information technology, or by formally creating lateral relations and adding liaison personnel and project managers).

Demand reduction approaches focus on repartitioning work in such a way that problem solving interdependencies are reduced, and thus the information processing requirements minimized (Burton and Obel 1984; Simon 1962). Increased information processing capacity is achieved through more integrative mechanisms such as enhanced information systems, overlapping phases of a project (Clark and Wheelwright 1992), defining special task forces or cross functional teams (Galbraith, 1973), or boundary spanning roles (Allen 1977).

From a theoretical standpoint, our results point the way to a more detailed micro-contingency theory (Burton and Obel 2003). Previous work, for example, does not address the point at which the benefits of interdependency (resulting from schedule compression) are outweighed by the costs (due to increased coordination and supervision work). We have shown how increasing interdependencies increases coordination problems at a nonlinear rate and how, in the extreme, these interdependencies lead to severe managerial failures, such as projects that never complete or projects that complete but with high quality risks. This provides a rationale for attempts to modularize project designs in an attempt to lower their coordination requirements.

Directions for future research

Simulations allow a researcher to explicitly constrain the number of variables and their causal interaction. The approach here is to build models based on field studies and to use a simulation platform (SimVision®) whose micro-behaviors have been validated in different settings over many years to perturb these empirically validated "baseline" work process and organization models. The focus here is on the "information flow physics" in various organizational designs, ignoring the "interpersonal chemistry". Thus, this research ignores the effects of individual variables, interpersonal interaction (aside

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from information flow), and contextual variables. Extending this work by including such factors would add a level of depth to these results.

Another opportunity to extend these results would be study different types of project teams. The exact number of tasks that may be made interdependent before the project duration increases, the exact number of additional personnel that may be employed before quality decreases, and so on depend on the particulars of our baseline models. However, our intent is not to delineate an exact number but rather demonstrate the direction of changes based on the approaches outlined and the interaction of the approaches. These results were robust across the case studies we used, and should translate to all similar situations – engineering oriented tasks where there is goal congruency and a reliance on well understood technical approaches to the task. Other situations may alter the relationships discovered here. For example, our results are also likely to be dependent upon the routineness and the decomposability of tasks. For nonroutine tasks, for example, higher levels of decentralization should permit higher quality decision making at the front levels of the project team, provided front level workers have high skill and experience, an assumption not included in our model.

Finally, project teams typically seek to minimize project completion time at an acceptable level of quality and cost. However, the "optimal" project design will depend on the relative weight of the benefits of project completion time in terms of cash flow, market share and competitive positioning compared to the costs of personnel time and lower quality. Thus, the optimal project design is a multidimensional response surface. Researchers have had some initial successes at defining "fitness functions" in terms of trade-offs among schedule, quality and cost for a specific project, and then using evolutionary computing techniques such as genetic programming to evolve more "optimal" configurations for the project organization and work process (KHosraviani et al. 2004). Where the firm wants to locate on this surface depends on strategic and contextual factors that are beyond the scope of this paper.

Figure 1: Methodology

Empirical: Interviews & Observation	Computational Emulation	Computational Virtual Experiments
Observe real-world project teams: • Org'l configuration • Task design	**Build computational baseline model:** • Org'l configuration • Task design	**Build alternative computational models:** • Degree of interdependency • Personnel, span of control • Centralization
Observe real-world outcomes	**Examine simulated outcomes**	**Analyze results**

① ② ③ ④ ⑤ ⑥

See Levitt (2004) for more on these steps.

Figure 2: Effect of Altering Task Interdependencies

Effect of Altering Task Interdependencies

Duration

1400
1200
1000
800
600
400
200
0

1   2   3   4   5   6

Number of Reciprocal Interdependencies
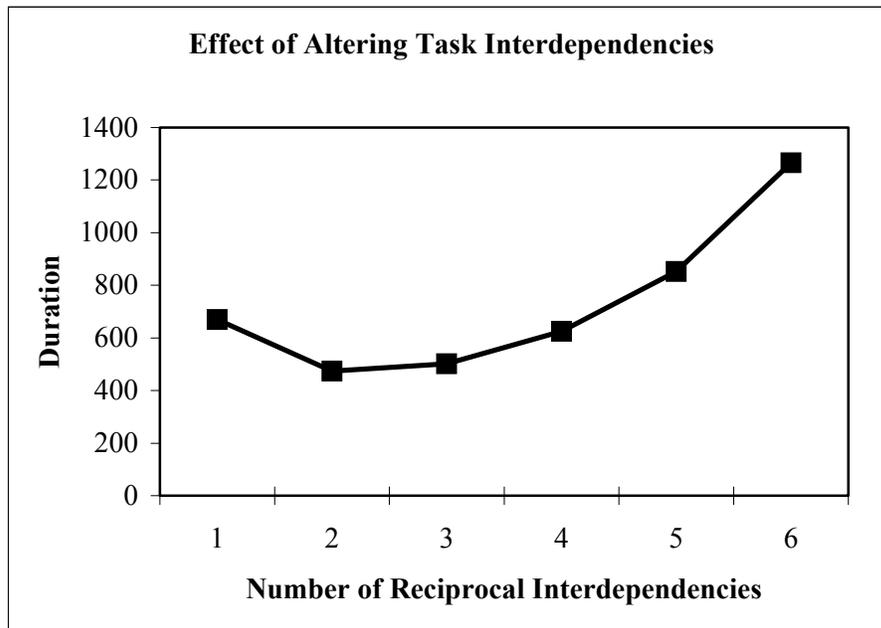
Figure 3: Effect of Adding Personnel (Duration)

Effect of Adding Personnel
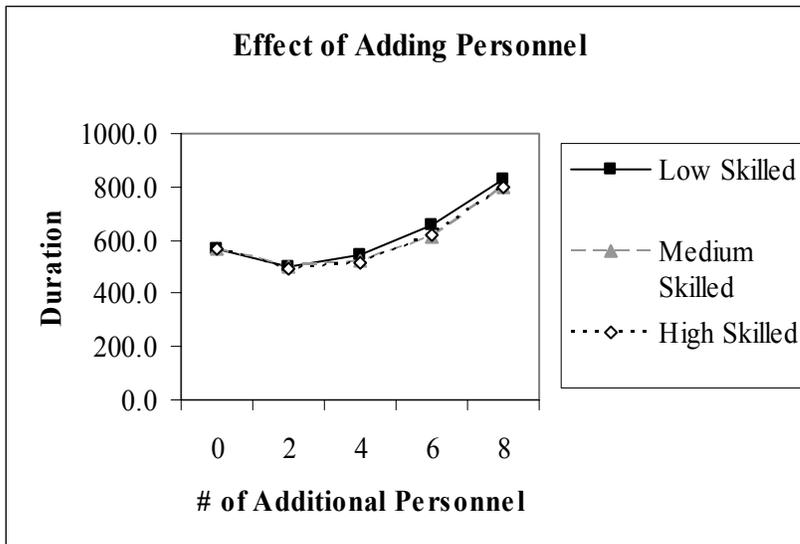
Figure 4: Effect of Decentralization

Effect of Decision Making
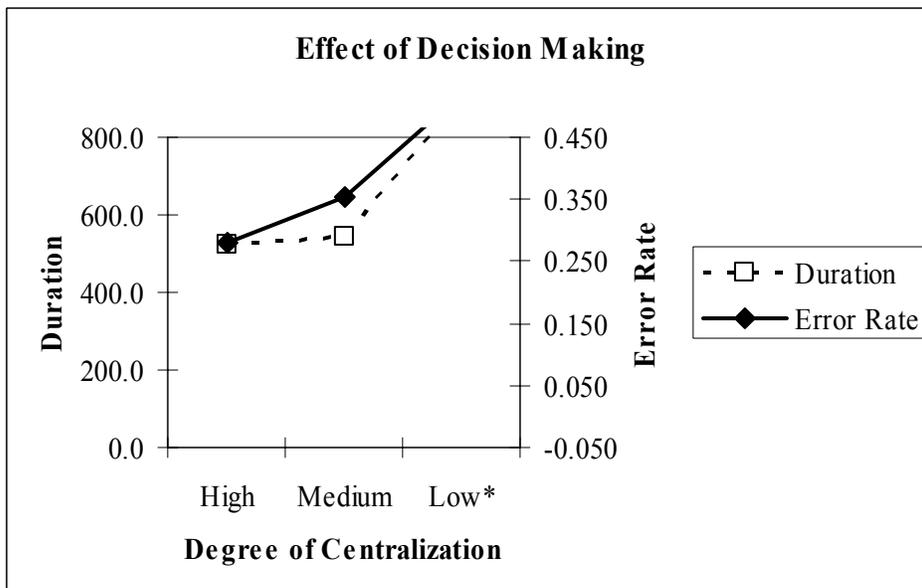
* Low centralization models would not calculate due to infinite errors and rework.

Table 1: Effect of Altering Task Interdependency

# Reciprocal Interdep.	Duration	Quality Measures		"Hidden Work" Measures		
		Functional Error Rate	Project Error Rate	Rework Volume	Coordination Volume	Decision Wait Volume
1	669.3	0.301	0.303	46.2	19.1	1.5
2	471.9	0.304	0.361	34.5	15.4	2.3
3	501.3	0.304	0.322	47.2	20.7	2.4
4	625.3	0.295	0.301	82.8	34.4	2.1
5	852.3	0.289	0.294	208.0	75.5	2.6
6	1265.4	0.284	0.286	404.5	142.9	3.6

Table 2: Effect of Adding Personnel

# Helpers	Duration	Quality Measures		"Hidden Work" Measures		
		Functional Error Rate	Project Error Rate	Rework Volume	Coordination Volume	Decision Wait Volume
Baseline	563.6	0.334	0.342	132.7	46.1	9.1
2 Add'l	501.9	0.333	0.389	120.1	51.8	10.4
4 Add'l	524.4	0.357	0.400	181.7	94.9	22.7
6 Add'l	609.7	0.385	0.413	293.7	188.5	57.2
8 Add'l	795.6	0.413	0.428	466.2	344.3	127.5

Table 3: Effect of Decentralization

Level of Centrali-zation	Duration	Quality Measures		"Hidden Work" Measures		
		Functional Error Rate	Project Error Rate	Rework Volume	Coordination Volume	Decision Wait Volume
Low	Models would not calculate due to infinite errors and rework.					
Medium	621.4	0.299	0.297	82.4	34.6	2.2
High	612.8	0.249	0.264	79.5	29.4	1.7

Table 4: Interaction between Reciprocal Interdependencies and Additional Personnel on Duration

	Number of Reciprocal Interdependencies					
	1	2	3	4	5	6
Baseline	659.85	474.80	494.10	487.60	761.37	974.80
2 Add'l	643.15	461.10	466.97	455.00	969.13	1178.77
4 Add'l	626.65	458.45	457.60	454.70	1022.80	1245.90
6 Add'l	615.75	457.70	452.13	461.90	1087.07	1283.10
8 Add'l	610.40	456.95	451.47	470.90	1120.43	1322.27

Table 5: Interaction between Reciprocal Interdependencies and Additional Personnel on the Project Error Rate

	Number of Reciprocal Interdependencies					
	1	2	3	4	5	6
Baseline	0.312	0.351	0.330	0.334	0.298	0.288
2 Add'l	0.310	0.351	0.323	0.368	0.296	0.286
4 Add'l	0.299	0.346	0.328	0.391	0.292	0.284
6 Add'l	0.299	0.343	0.326	0.388	0.291	0.287
8 Add'l	0.305	0.340	0.321	0.391	0.294	0.285

BIBLIOGRAPHY

Adler, P. S. 1995. Interdepartmental Interdependence and Coordination: The Case of the Design/Manufacturing Interface. *Organization Science*. **6** (2): 147-167.

Allen, T. J. 1977. *Managing the Flow of Technology*. MIT Press, Cambridge, MA.

Ancona, D. G., D. F. Caldwell. 1992. Bridging the Boundary: External Activity and Performance in Organizational Teams. *Administrative Science Quarterly*. **37** 634-665.

Bailetti, A. J., J. R. Callahan, S. McCluskey. 1998. Coordination at Different Stages in the Product Design Process. *R & D Management*. **28**(4) 237-247.

Brooks, F. P. 1974. *The Mythical Man-Month: Essays on Software Engineering*. Addison-Wesley, Reading, MA.

Burton, R. M., B. Obel. 1980. A Computer Simulation Test of the M-Form Hypothesis. *Administrative Science Quarterly*. **25** 457-66.

—, —. 1984. *Designing Efficient Organizations: Modeling and Experimentation.* Elsevier Science, Amsterdam.

—, —. 2003. *Strategic Organization Diagnosis and Design: The Dynamics of Fit*. 3rd Edition. Kluwer Academic Publishers.

Christiansen, T.R. 1993. *Modeling Efficiency and Effectiveness of Coordination in Engineering Design Teams*. Unpublished Ph.D. Dissertation. Department of Civil and Environmental Engineering, Stanford University, Stanford, CA.

Cohen, G.P. 1992. *The Virtual Design Team: An Object-Oriented Model of Information Sharing in Project Teams*. Unpublished Ph.D. Dissertation. Department of Civil Engineering, Stanford University, Stanford, CA.

Clark, K. B., S. C. Wheelwright. 1992. Organizing and Leading 'Heavyweight' Development Teams. *California Management Review*. **34**(3) 9-28.

Darwiche, A., R. E. Levitt, B. Hayes-Roth. 1988. OARPLAN: Generating Project Plans by Reasoning about Objects, Actions, and Resources. *Artificial Intelligence for Engineering Design, Analysis, and Manufacturing*. **2**(3) 169-181.

Galbraith, J. R. 1973. *Designing Complex Organizations*. Addison-Wesley, Reading, MA.

Galbraith, J. R. 1974. Organization Design: An Information Processing View. *Interfaces*. **4**(3) 28-36.

Galbraith, J. R. 1995. *Designing Organizations: An Executive Briefing on Strategy, Structure, and Process*. Jossey-Bass, San Francisco.

Gresov, C. 1989. Exploring Fit and Misfit with Multiple Contingencies. *Administrative Science Quarterly*. **34** 431-453.

Hansen, M. T. 1999. The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organizational Subunits. *Administrative Science Quarterly*. **44** 82-111.

Henderson, R. M. I. Cockburn. 1994. Measuring Competence? Exploring Firm Effects in Pharmaceutical Research. *Strategic Management Journal*. Winter Special Issue. **15** 63-84.

Jacques, E. 1998. *Requisite Organization: A Total System for Effective Managerial Leadership for the 21st Century*. 2nd Edition. Cason Hall & Company.

Imai, K., I. Nonaka, H. Takeushi. 1985. Managing the New Product Development Process: How Japanese Companies Learn and Unlearn. In *The Uneasy Alliance: Managing the Productivity-Technology Dilemma*. K. B. Clark, R. Hayes, and C. Lorenz (Eds.). Harvard University Press, Boston.

Kelley, H. H., J. W. Thibaut. 1978. *Interpersonal Relations: A Theory of Interdependence*. John Wiley & Sons, New York.

Kim, J., R. M. Burton. 2002. The Effect of Task Uncertainty and Decentralization on Project Team Performance. *Computational and Mathematical Organization Theory*. **8**(4) 365-384.

KHosraviani, B., R. E. Levitt, Koza, J. R. Koza. 2004. Organization Design Optimization Using Genetic Programming. CASOS conference, Pittsburgh, PA.

Kowtha, N.R. 1997. Skill, Incentives and Control. *Group & Organization Management*. **22** 53-86.

Latane, B., K. Williams, S. Harkins. 1979. Many Hands Make Light Work: The Causes and Consequences of Social Loafing. *Journal of Personality and Social Psychology*. 822-32.

Lawrence, P.R., J. W. Lorsch. 1967. Organization and Environment: Managing Differentiation and Integration. Harvard University Press, Cambridge, MA.

Levitt, R. E., G. P. Cohen, J. C. Kunz, C. I. Nass, T. Christiansen, Y. Jin. 1994. The 'Virtual Design Team': Simulating How Organization Structure and Information Processing Tools Affect Team Performance. In K. M. Carley and M. J. Prietula (Eds.), *Computational Organization Theory*. Lawrence Erlbaum Associates, Hillsdale, NJ.

Levitt, R. E. 2004. Toward an Information-Processing Micro-Contingency Theory of Knowledge Work. Working Paper # 4. Collaboratory for Research on Global Projects. Stanford University, Stanford, CA.

Mackenzie, K. D. 1974. Measuring a Person's Capacity for Interaction in a Problem Solving Group. Organizational Behavior and Human Performance. **12** 149 – 169.

March, J. G. 1988. *Decisions and Organizations*. Basil Blackwell, Oxford.

March, J. G., H. A. Simon. 1958. *Organizations*. Wiley, New York.

Pfeffer, J., G. R. Salancik. 1978. *The External Control of Organizations: A Resource Dependence Perspective*. Harper and Row, New York.

Porras, J. I., J. Collins. 1994. *Built to Last*. Harper Business.

Simon, H. A. 1976. *Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization*. Free Press, New York.

Staudenmayer, N. 1997. *Managing Multiple Interdependencies in Large Scale Software Development Projects*. Unpublished Ph.D. Dissertation. Massachusetts Institute of Technology, Cambridge, MA.

Thompson, J. D. 1967. *Organizations in Action*. McGraw-Hill, New York.

Thomsen, J., M. Fischer, R. E. Levitt. 1998. The Virtual Team Alliance (VTA): An Extended Theory of Coordination in Concurrent Product Development Projects. Working Paper #44, Center for Integrated Facility Engineering, Stanford University.

Wageman, R. 1995. Interdependence and Group Effectiveness. *Administrative Science Quarterly*. **40** 145-180.

Weick, K. E. 1990. Technology as Equivoque: Sensemaking in New Technologies. In *Technology and Organizations*. P. S. Goodman (Ed.). Jossey-Bass, San Francisco.

Wheelwright, S. C., K. B. Clark. 1992. *Revolutionizing Product Development*. Free Press, New York.

Yetton, P., P. Bottger. 1983. The Relationships among Group Size, Member Ability, Social Decision Schemes, and Performance. *Organization Behavior and Human Performance*. 145-59.