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Cooperative Planning, Uncertainty, and Managerial Control in Concurrent Design

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We examine whether cooperative planning and uncertainty affect the magnitude of rework in concurrent engineering projects with upstream and downstream operations, and explore the impact of such rework on project delays. Using survey data from a sample of 120 business process (BP) redesign and related information technology (IT) development projects in healthcare and telecommunications, our results indicate that upstream (BP) rework and downstream (IT) rework is mediated and mitigated by cooperative planning through upstream/downstream strategy coupling and cross-functional involvement. In addition, uncertainty related to a lack of firm or industry experience with such projects increases the magnitude of upstream rework but not downstream rework or the amount of cooperative planning. After accounting for project scope, implementation horizon and whether delays are anticipated, we find that project delay is primarily influenced by the magnitude of downstream rework and downstream delay: the magnitude of both upstream and downstream rework significantly increases downstream delay, which significantly increases project delay. However, the magnitude of upstream rework does not directly affect project delay. These results suggest that project delay is under managerial control as cooperative planning is a managerial function that reduces downstream rework, while uncertainty from a lack of experience with the design affecting upstream rework is not directly under managerial control.

Key words: concurrent design; uncertainty; coordination; cooperative planning; concurrent engineering; project management; delay; process redesign; rework
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1. Introduction

The engineering design problem most often examined in the literature on concurrency, uncertainty, and coordination is a two-stage operation where upstream operations provide elements of the project to downstream operations. Development activities in projects where operations in the two stages are overlapping and interdependent is *concurrent design*, and concurrent design involves the use of preliminary design information for coordination (Krishnan and Ulrich 2001). Concurrency in design operations is challenging to manage because interdependent design decisions may be ignored or may change over different stages of development. These interdependent design decisions often lead to rework—which we define as design change whose implementation alters work that was previously done upstream and downstream. Rework has a frequency dimension (number of change iterations) and a magnitude dimension (amount of change) relative to the original design. Rework can occur in one or more stages and this can lead to project delay, where project delay is defined as the time between planned and actual project completion.

Two aspects of concurrent design affecting project completion, through design rework, are uncertainty and coordination. Uncertainty and coordination are related, as greater uncertainty requires greater coordination to define and implement the design (Galbraith 1974). Analytical models indicate that project delays result from excessive iteration for rework related to uncertainty (Krishnan et al. 1997), and excessive communication for coordination (Loch and Terwiesch 1998). Early resolution of uncertainty, when design requirements are known and stable, mitigates the risk of project delay (Terwiesch and Loch 1999). However, uncertainty from fit novelty, where design exceptions increase with the organization's inexperience with the design's fit issues (Adler 1995), and unforeseeable uncertainty, where relevant variables and their functional relationships cannot be recognized (Sommer and Loch 2004), can both prohibit early resolution. Under these conditions, different forms of coordination—cooperative planning and dynamic adjustment—may be the most effective means of dealing with uncertainty.

Product design is defined as a transformation of a market opportunity and technology possibilities into a design solution (Krishnan and Ulrich 2001, Gerwin and Barrowman 2002), and the focus in the literature has been on the design of complex products such as automobiles, aerospace systems, software, and industrial equipment (Mihm et al. 2003). This design shares the same characteristics as IT-dependent process redesign projects in dynamic environments. Krishnan and Bhattacharya (2002) describe two-stage design as an upstream product definition stage where input data and information about customer needs and emerging technologies are used to finalize key specifications, and these specifications are used downstream in detailed design and prototyping. Similarly, business process (BP) redesign and information technology (IT) development involves gathering and redefining business rules and functional requirements together with emerging technology options upstream, and using these requirements and technology options to develop detailed IT design and implementation solutions downstream.

One means of controlling the amount of rework resulting in project delay is to mitigate the uncertainty associated with fit novelty. A primary concern in BP redesign and related IT development is the fit between IT capabilities and BP requirements—a form of fit novelty. Uncertainty surrounding the fit between BP and IT increases when BP design parameters are more sensitive to IT decisions (or vice versa), when an organization has less experience resolving problems related to BP-IT interdependence, and the more innovative the BP design or IT platform. Consequently, greater fit novelty requires greater coordination between upstream and downstream operations (Adler 1995).

In the early phases of a project (visioning and design), an effective means of coordination is the pre-communication between upstream and downstream operations (Loch and Terwiesch 1998). One form of pre-communication is cooperative planning, where the early resolution of uncertainty is contingent on the level of strategy coupling and cross-functional involvement (Mitchell and Zmud 1999). Strategy coupling facilitates the exchange of preliminary information necessary for early requirements specification, and cross-functional involvement in the planning process promotes information precision and stability in setting design specifications. The degree of cooperative planning is a coordination mechanism that management controls.

Prior concurrency research has highlighted the effects of uncertainty and coordination on the frequency of rework and project delay primarily though analytical modeling. We conduct a confirmatory field study at the micro-level that empirically tests these theoretical relationships to determine the extent to which, in practice, the magnitude of rework and project delay in concurrent design is under managerial control. Our research is guided by the following questions: (1) Does greater cooperative planning reduce the magnitude of upstream and downstream rework, and does it mediate the relationship between upstream and downstream rework? (2) Does greater uncertainty increase the magnitude of upstream and downstream rework? (3) Does the magnitude of rework affect the duration of project delay?

We study 120 BP redesign and IT development projects in the healthcare and telecommunications sectors where upstream BP design and downstream IT platform design are interdependent. Using a Partial Least Squares (PLS) model and a magnitude of rework scale we develop based on Henderson and Clark's (1990) types of design change, we find strong results about the decoupling of downstream delay from upstream uncertainty through cooperative planning, and about the impacts of uncertainty and complexity. Specifically, we find that greater cooperative planning reduces the magnitude of both upstream and downstream rework. We also find that greater uncertainty from a lack of prior experience with the design affects the magnitude of upstream rework but does not significantly affect the magnitude of downstream rework. Moreover, the PLS analysis indicates that cooperative planning mediates the relationship between upstream and downstream rework such that in the presence of cooperative planning the direct effect of upstream rework on downstream rework is not significant. In addition, we find that more extensive downstream rework leads to longer downstream delay, and these in turn lead to longer overall project delay. In contrast, more extensive upstream rework does not directly lead to longer project delay, but does lead to longer downstream delay. These results suggest that the duration of project delay is under managerial control, primarily through cooperative planning that reduces the magnitude of upstream and downstream rework as well as downstream delay.

The remainder of this paper proceeds as follows. First, we examine the literature on concurrent design, highlighting studies of uncertainty and of coordination. Next, we provide an example illustrating BP-IT interdependencies. Then, we describe our methodology with the research model, instrument development, and data collection. Subsequently, we present our PLS analysis and our results. We finish with our discussion and conclusion summarizing the results, outlining the limitations of our study, and describing the implications for future research and for practice.

2. The Literature on Concurrency, Uncertainty, and Coordination

In a classic study of the auto industry, Clark and Fujimoto (1989) describe the product development process as a set of information processing activities for problem solving. In an overlapping, or concurrent, approach upstream operations release preliminary information to downstream operations before the upstream information is finalized. This preliminary upstream information is used downstream to forecast final outcomes of upstream activity. Downstream activity based on this forecast starts before upstream output is complete and may provide feedback upstream. Inaccurate downstream forecasts of upstream output result in rework, whereby work previously done downstream based on preliminary design forecasts must be updated with the revised upstream output results. Hence, concurrency without appropriate coordination may reduce design quality and create project delay due to mismanagement of information and uncertainty between upstream and downstream activities.

Henderson and Clark (1990) delineate four categories of technological design change in product development—incremental, modular, architectural, and radical—whose progression is related to the magnitude of effort in altering the core design of system components and/or how those components are linked together. Borrowing these categories to define the magnitude of rework, we relate the degree of upstream and downstream rework to an incremental-radical continuum that captures the level of deviation from the intended process (or platform) design. Where incremental rework involves minor design change, modular, architectural, and radical rework involves major design changes to varying degrees. Modular rework is limited to major changes in process or platform components, architectural rework entails major changes to linkages, and radical rework involves major changes to both components and linkages. Henderson and Cockburn (1994) argue that due to complexities of system interdependence, design change involving linkages (architectural and radical) are more difficult to enact than those confined to components (modular).

The magnitude of rework reflects the nature of design uncertainties left unresolved, in part due to project complexity. In a model examining limits to concurrency and the causes of cycle time expansion, Hoedemaker et al. (1999) find that the usefulness of concurrency is limited by project complexity. In concurrent design, the communication burden increases in proportion to the degree of task subdivision, and a higher degree of task subdivision increases potential integration problems and the likelihood of rework. Joglekar et al. (2001) find that concurrent engineering need not be the optimal work strategy in many settings and management must consider information exchanges, rework issues, performance thresholds, and resource restrictions.

2.1. Uncertainty

When downstream operations start work before upstream operations have finalized their problem solving, uncertainty related to fit novelty can result from a lack of prior experience with the design task (Adler 1995). In this context, uncertainty is the absence of complete information about an organizational phenomenon, which in turn leads to an inability to predict its outcome (Argote 1982). Where the task is concurrent BP redesign and IT development, uncertainty refers to an absence of information needed to identify and implement new BP and IT specifications. Consequently, redesign projects that are unable to resolve design uncertainties early are less able to determine design specifications and information requirements.

Terwiesch and Loch (1999) find evidence to support benefits of rapid uncertainty resolution, where uncertainty resolution is the proportion of project time taken to progress from concept definition to the final design specification. This uncertainty in the knowledge of one operation about the other does not influence project duration directly but rather moderates the impact of concurrency on project duration. Early uncertainty resolution makes overlap between project operations more successful and the significant advantage of concurrency disappears with slower uncertainty resolution.

McFarlan (1981) recognized that uncertainty requires adapting management style to the project uncertainty profile as measured by project size, project structure, and experience with the technology. An additional dimension of uncertainty is the complexity related to project scope (Mihm et al. 2003), which stems from the number of subsystem interactions (Simon 1976). Adler (1995) refers to this as fit analyzability, defined as "the difficulty of the search for an acceptable solution to the given fit problem" (p. 158). Analyzability decreases with the number of units involved, and low analyzability creates design ambiguity. Sommer and Loch (2004) distinguish between types of complexity and report that interaction complexity is more damaging to project outcomes than system size complexity. Interaction complexity increases with project scope as process interfaces introduce ambiguous interdependencies that may be difficult to predict (Schrader et al. 1993).

Although we do not address it here, other work has examined technology uncertainty—that is, whether the technology itself is novel (e.g., Clark and Wheelwright 1993, Krishnan and Bhattacharya 2002, Tatikonda and Rosenthal 2000), and issues of information inadequacy (e.g., Pich et al. 2002).

2.2. Communication and Coordination

Smith and Eppinger (1997) note that engineering design often involves a complex set of relationships among a large number of coupled problems. It is this complex coupling that leads to iterations among engineering tasks. Fewer iterations and less extensive rework may be experienced when coupled development activities can anticipate each others' results, and the consequence of such coordination can be fewer and shorter project delays. This coordination can be facilitated through communication.

Following Adler (1995), Loch and Terwiesch (1998) define two types of communication for coordination. First is pre-communication such as standards, schedules, and plans that occur early in a project. The second is concurrent communication such as dynamic adjustments between teams as the project unfolds. Analytically examining the trade-off between gains in time from concurrent tasks and the costs of rework, they find that optimal levels of concurrent communication increase with uncertainty and dependence, and that higher levels of uncertainty and dependence make concurrency less attractive.

In linking communication and concurrency, Blackburn et al. (1996) indicate that if interdependencies cannot be eliminated, they must be managed. The involvement of downstream functions in upstream design activities—frontloading—is critical in defining design specifications because functional requirements are volatile. When designs are based on volatile functional requirements and these requirements change, the design changes that must be implemented to satisfy the change in requirements are the chief cause of rework. A flying start or flow forward of preliminary information is needed to begin downstream work. Although we do not address it here, other work has focused on imperfect preliminary information (Terwiesch et al. 2002), and the continuous release of preliminary information (Mihm et al. 2003).

Preliminary information exchange can take place through cooperative planning. In the context of BP redesign and IT development, one aspect of cooperative planning is strategy coupling where IT decisions are made in conjunction with a firm's BP strategy (Boynton and Zmud 1987) and BP design decisions consider IT capabilities, limitations, and future development (Lederer and Mendelow 1989). The degree of coupling ranges from tight to loose, reflecting the amount of joint planning during pre-communication. Tight strategy coupling requires a high degree of cooperation and joint planning up front for the early resolution of design uncertainty. In contrast, loose strategy coupling relies on feedback-driven adjustments during implementation and less joint planning during pre-communication to promote design flexibility (Horwitch and Thietart 1987). Adler's (1995) findings suggest that with greater fit novelty, coordination through cooperative planning requires tight coupling to resolve uncertainty.

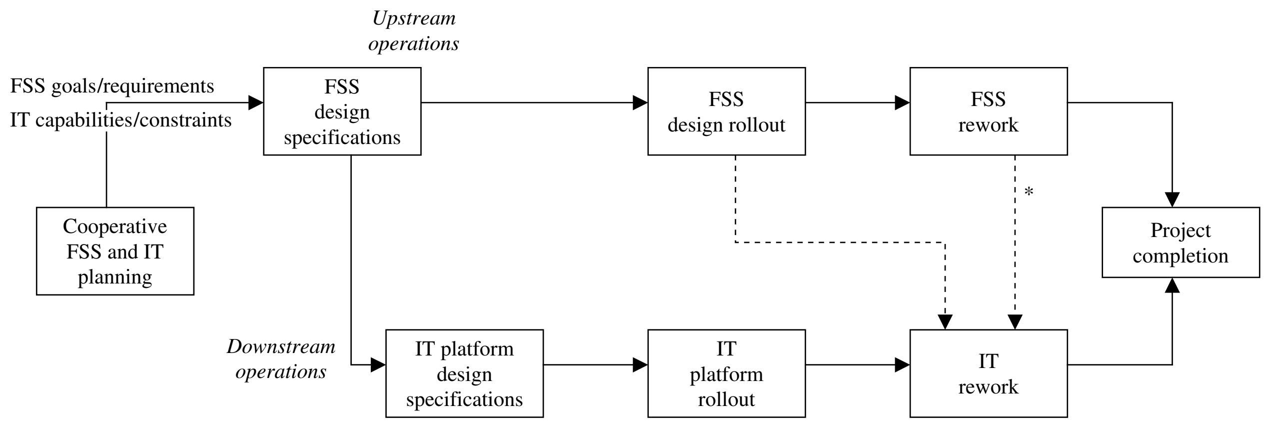
In one of the few empirical studies on BP-IT strategy coupling and project performance, Mitchell and Zmud (1999) found that under uncertainty tight BP-IT strategy coupling was more effective in minimizing project delay than loose coupling. Tight coupling allowed for the early identification of IT constraints in meeting functional requirements while establishing the BP vision. Loose coupling resulted in "wasteful overcoordination" complicating the design process with formal planning mechanisms (Adler 1995). Sabherwal and Chan (2001) report that the degree of IT support for business strategies is highly correlated with business performance. A related aspect of cooperative planning is cross-functional involvement. Lederer and Mendelow (1989) found that a lack of communication of even well-defined plans between business and IT units impedes project coordination and that cooperative planning by way of cross-functional involvement improves performance. Measuring the linkage between business and IT strategies, Horner-Reich and Benbasat (1996) also found that cross-functional involvement led to an understanding of each other's objectives and a common vision of their respective roles relative to the firm's mission.

3. Concurrency Design—The Frozen Section Service at UHT

We highlight the dependency structure between upstream and downstream operations in the following redesign project. The University Hospital of Tromso (UHT), Norway, redesigned their remote consultation processes to co-locate patient and medical information rather than physically co-locate patient and specialist. One such process was the frozen section service (FSS) frequently used for pathology consultation. FSS is a diagnostic process where a specimen is frozen, cut, stained, and examined within 20 minutes of excision. UHT redesigned their FSS such that it could be performed remotely using specialized video conferencing equipment, a motorized robotic microscope, and a remotely operated macrocamera. (Hartviksen and Rinde 1993). Although UHT faced a moderate level of fit novelty in its FSS design (Nordrum 1991), concurrency in FSS redesign and IT development was successful, in large part due to a high level of cooperative planning between upstream (FSS) and downstream (IT) operations.

We use Figure 1 to conceptualize the concurrency structure between upstream and downstream operations in our example. We recognize the potential for activity overlap *within* operations, however we focus exclusively on activity overlap *between* operations and the role of pre-communication in reducing the magnitude of rework affecting project delay. A significant amount of design uncertainty was resolved early through cooperative planning (pre-communication) between the pathology department and IT department. This form of pre-communication

Figure 1 UHT Upstream-Downstream Relationships



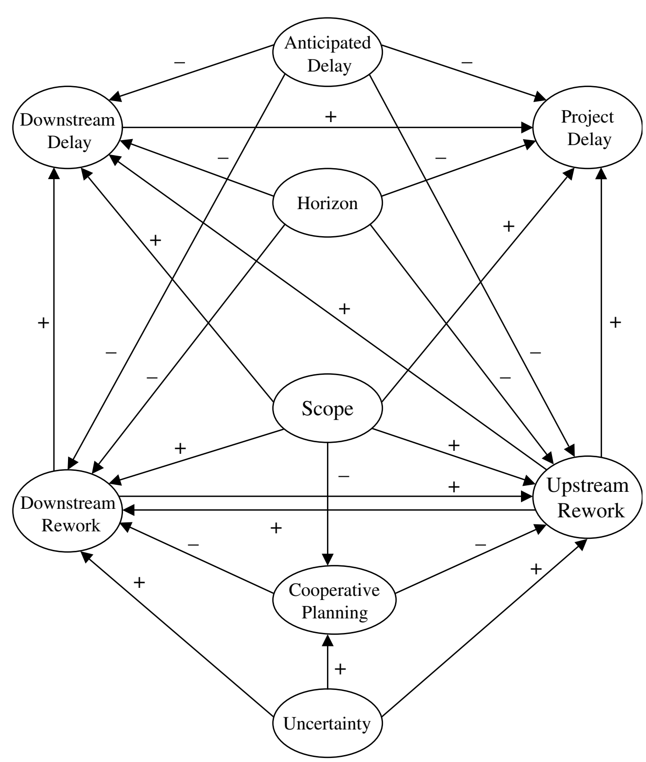
*Mediated by the level of cooperative planning.

permitted joint consideration of FSS goals and functional requirements with IT capabilities and constraints in formulating a new FSS design. FSS design specifications gave rise to IT platform specifications in the joint evolution of service delivery and IT support. In the course of FSS rollout and IT rollout, technology and process difficulties arose requiring FSS rework and IT rework. For example, the substitution of lab technicians for surgeons in the preparation of frozen-section slides necessitated FSS changes to the preparation process. Greater reliance on the remote pathologist for specimen examination mandated better image quality. Image distortions resulted in IT changes to improve the quality of codec equipment in the interactive video system and utilization of the fiber-optic network instead of coaxial cable. Image degradation when a slide was moved on the microscope stage was also problematic for pathologists. Four pre-transmission methods for image quality improvement were tried where the pathologist refined the image through contrast enhancements, shading corrections, noise reduction, and haze removal. Contrast enhancement and noise reduction were also applied post-transmission to correct for image distortion by compression and decompression algorithms used in the transmission process (Danielson 1993). The dynamic communication between pathologists and IT personnel resulted in feedback-driven adjustments to the robotic microscope and video workstation. The realized (final) FSS/IT designs implemented incorporated modifications stemming from FSS/IT rework. The project came in on time and within budget.

4. Research Model

To answer our research questions, we make use of the model in Figure 2. The direction of the lined arrows between latent variables, or paths, indicates the causal direction of the relationships. The construct we wish to explain is the duration of Project Delay. In the context of BP redesign and IT development projects, project performance as a process refers to efficiency in planning and implementation that is reflected in the duration of project delay. Project Delay is the difference between actual and planned project completion dates. In our model, the duration of Project Delay is caused by unplanned Upstream (BP) Rework and by the duration of Downstream (IT) Delay. Because our downstream operation (IT development) is subject to formal IT plans with scheduled milestones, we model Downstream Delay—reflecting the differ-

Figure 2 Research Model



ence between actual and planned IT implementation dates—as slippage caused by Downstream Rework. A greater magnitude of Downstream Rework directly increases the duration of Downstream Delay, and upstream delays from Upstream Rework may also translate into Downstream Delays, and these delays in turn increase the duration of Project Delay. The magnitude of Upstream Rework also has a direct effect on the duration of Project Delay.

The literature argues that Upstream and Downstream Rework can be mitigated through Cooperative Planning, whereby greater Cooperative Planning lowers the amount of Upstream and Downstream Rework. Moreover, Cooperative Planning is seen to mediate the relationship between Upstream and Downstream Rework. Uncertainty causes more trial and error, and the analytical literature indicates that greater Uncertainty results in more Upstream and Downstream Rework. This literature also indicates that management can adjust the degree of Cooperative Planning based on the level of Uncertainty and complexity (Scope) characterizing a project. Finally, we expect a relationship between the magnitude of Upstream Rework and Downstream Rework such that the greater the magnitude of Upstream Rework, the greater the magnitude of Downstream Rework. However, with Cooperative Planning as a mediator, this relationship should be weak.

Our research model also includes controls for project complexity, size, and whether delays are anticipated. We measure project complexity as Project Scope because the more entities (functional areas and firms) involved in a project, the greater the system interdependencies that increase design complexity (Lawrence and Lorsch 1967). Thus, we focus on the reach (across functional areas and firms) dimension of a project's scope as a proxy for complexity. We expect as Project Scope increases, so will the magnitude of rework and the duration of delay. Adler's (1995) fit analyzability supports the need for less Cooperative Planning as complexity increases, allowing flexibility to deal with greater ambiguity in BP-IT design across business units and facilities. This indicates that the loose coupling of plans is more effective in complex projects, and we expect the amount of Cooperative Planning to fall as Project Scope increases.

Implementation horizon is the planned duration of the project. We use Implementation Horizon as a proxy for the size of the combined BP-IT design projects because the size of a redesign project (e.g., number of functional areas/firms involved, workers or customers affected, percentage of front/back office activity, or resource expenditures) is measured differently than size of an IT development project (e.g., number of hardware components, interfaces, network configuration, lines of code, man-months, or IT expenditures). The projected Implementation Horizon takes these various measures of size into account in setting an initial project completion date. Thus, Implementation Horizon is a forecast of the time needed to plan and enact the intended upstream and downstream operations accounting for their respective size. All other factors equal, we expect a longer Implementation Horizon to result in less rework and shorter delays. Finally, Anticipated Delay is whether the most critical delay in the project was anticipated. Although not a measure of intended versus unplanned rework (Safoutin and Smith 1998), it measures whether delays could be foreseen and built into the Implementation Horizon. We expect anticipation of the most critical delay to reduce both rework and delays.

5. Methodology

5.1. Instrument Development

Our survey instrument is available in the appendix. Our measure of Uncertainty is a composite of five survey items, PM1–PM5. These items replicate Mitchell and Zmud's (1999) process innovation instrument measuring the extent to which the process being redesigned is different from other process designs in the firm and in the industry. As such, they conform to Adler's (1995) fit novelty, the number of exceptions with respect to organizational experience, and this fit novelty creates uncertainty. They are also similar to measures used in Tatikonda and Rosenthal (2000), where a lack of newness or "technology novelty" served as a proxy for the availability of prior knowledge that can mitigate uncertainty. The responses were collected on a 7-point Likert scale and three items were reverse coded so that each of the items reflects increasing Uncertainty.

Our measure of Cooperative Planning, representing the strategy coupling and cross-functional involvement between the upstream and downstream operations, is a composite of nine survey items collected on a 7-point Likert scale, ITM1–ITM9. Six items, obtained from Mitchell and Zmud's (1999) IT and work process coupling instrument, measure the level of joint planning between upstream BP design and downstream IT design. The remaining three items, which reflect cross-functional involvement in IT and BP implementation (IT consultation, redesign goal clarity, and the exploitation of IT capabilities), were derived from the reengineering and technological change literature (Davenport 1993, Hammer 1990, McDonald 1991). This measure of Cooperative Planning reflects Adler's (1995) static coordination (by plan) and Loch and Terwiesch's (1998) pre-communication. It does not capture dynamic design adjustments between teams reflecting ongoing changes as the project unfolds.

As discussed in the prior section, we measured two variables to control for the scale of the design project as the magnitude of rework and the potential for delays may depend on the size and complexity of the project (Blackburn et al. 1996), and another variable to control for whether the most critical delay was anticipated. The first control is Project Scope. Project managers were asked about the project's scope in terms of increasing functional reach: (1) isolated to a functional area within the firm, (2) spans multiple functional areas within the firm, (3) spans a single function area across multiple firms, and (4) spans multiple functional areas across multiple firms. This scale serves as a proxy for project scope in that it captures increasing levels of complexity associated with greater functional area and firm interdependencies. The second control is Implementation Horizon, which is measured as the accumulated time from the project start date to the scheduled completion date. This serves as a proxy for the overall size of the project. The third control is Anticipated Delay, measured as a dummy variable representing whether the most critical delay was anticipated.

To capture the magnitudes of upstream and Downstream Rework, we develop Guttman scales based on Henderson and Clark's (1990) typology of design change. In developing a Guttman scale for Upstream Rework and Downstream Rework, we base the magnitude of rework on the nature of design change associated with each change type progressing from (1) incremental, (2) modular, (3) architectural, and (4) radical. We use wording in our survey questions to identify the type of design change and the knowledge necessary for those changes as per Henderson and Clark (1990).

Departing from the traditional measure of rework as the frequency of change, our measure captures another dimension of rework—the magnitude of change. In the BP-IT context, the design methodology influences frequency measures of rework. For example, Agile IT development methods (e.g., Extreme Programming) use an iterative process of feedback-driven adjustments between programmers and users until a functional design emerges. Frequent rework forms the basis of this approach because daily builds and "refactoring" (design change) are what facilitate uncertainty reduction and timely project completion. In contrast, the traditional waterfall approach freezes design specifications as implementation begins, and rework is considered an exception. Our measure of the magnitude of rework—types of design change as per Henderson and Clark (1990)—are not influenced by the design methodology as the magnitude of rework represents the aggregation of design changes to the initial BP and intended IT designs.

To assess the face validity and structure of our measurement scales, we sent the survey instrument to project managers and IT managers in two healthcare firms and two telecommunication firms. These managers were asked to evaluate the degree to which the survey questions captured the intended concepts, and were interviewed by telephone to obtain their feedback. This feedback was incorporated in the final survey instrument.

5.2. Data Collection

Our sampling frame consisted of BP redesign and IT development projects implemented over the last 12 years in the US telecommunication and health care sectors. Concurrent design initiatives were identified through consulting agencies, government agencies, and professional associations. Where the contact person for a project was not provided, we phoned a member of the top management team who did provide this information. Project managers and IT managers were contacted by phone and informed of the study. The two managers were separate individuals and there was no hierarchical reporting relationship between them. Of those contacted, 143 sets of managers agreed to participate. Managers were interviewed by phone to collect data about BP redesign and IT development projects initiated within the previous six months—specifically about project goals, the targeted process, projected and actual completion dates, and the nature of Project Delays. Once projects were completed, questionnaires were distributed, and 120 matched sets across the participant categories were returned—25 sets in telecommunications and 95 sets in health care—yielding a response rate of 84%.

In designing our study, we targeted our questions to the managers most knowledgeable about the subject of the questions. Using separate respondents reduces the threat to internal validity that could come from the same respondents providing all the variables in the model (Campbell and Stanley 1963). In our interview data, we found that IT design was consistently based on BP design and corporate goals, and that past project time and budget overruns in IT caused firms to use concurrent design—resulting in substantial operations overlap—to shrink the development life cycle. None of our projects were first movers in hardware, network, or standards development although some projects had to customize vendor-developed and packaged software. Thus, uncertainty stemmed primarily from novelty in BP design rather than innovation in IT design. Consequently, project managers were queried about Uncertainty, Project Scope, Implementation Horizon, Anticipated Delay, and Project Delay. IT managers were queried about Cooperative Planning and IT Delay. Both sets of managers were queried about BP Rework and about IT Rework. Only one project per firm was included in the study.

Table 1 Descriptive Statistics, Principal Components Analysis Loadings, PLS Item Loadings, and Composite Reliability

	Mean	Std. dev.	Principal component-1 Cooperative planning	Principal component-2 Uncertainty	Item loadings
Cooperative Planning items—IT manager: *Composite reliability* = 0.965					
ITM1. The company has an IT strategic plan	4.69	2.30	0.846	0.198	0.8413
ITM2. IT strategy supports the redesign project's strategy	4.73	2.01	0.895	−0.103	0.8535
ITM3. Business unit managers are involved in IT planning	4.28	1.95	0.882	0.152	0.8639
ITM4. IT specialists were consulted prior to implementing the redesign project	4.48	2.09	0.864	−0.026	0.9069
ITM5. The goals of the redesign project were made clear to the IS staff	4.44	2.05	0.814	0.228	0.7880
ITM6. IT capabilities were recognized and exploited by the new process design	4.34	2.05	0.833	−0.074	0.8769
ITM7. The info/IT needs of the redesign project were considered when forming the IT plan	4.48	1.99	0.851	0.209	0.8271
ITM8. An assessment of IT strengths and limitations was utilized by the redesign plannersby the redesign planners	4.26	1.98	0.919	−0.076	0.9272
ITM9. Assessment made of relevant IT trends prior to implementing the redesign project	4.61	2.02	0.910	−0.014	0.9175
Uncertainty items—Project manager: *Composite reliability* = 0.964					
PM1. The redesigned process chosen was a de facto industry standard†	3.47	2.02	0.059	0.883	0.8902
PM2. The redesigned process was unique to this company, no one else is using it	3.32	1.92	0.073	0.945	0.9418
PM3. This design was adopted because of its proven usefulness in the industry†	3.32	1.82	0.013	0.943	0.9417
PM4. The redesigned process was a major departure from previous operations	3.28	1.90	0.074	0.934	0.8901
PM5. The redesigned process is similar to process designs used in other areas of the company†	3.23	1.86	0.020	0.868	0.9283
Frequency of other variables					
IT Delay (none = 29, 1–3 mos. = 48, 4–6 mos. = 16, 7–9 mos. = 12, 10–12 mos. = 10, >1 yr. = 5)	4.08	4.62			
Project Delay (none = 21, 1–3 mos. = 52, 4–6 mos. = 12, 7–9 mos. = 17, 10–12 mos. = 13, >1 yr. = 15)	6.43	8.16			
BP Rework (incremental = 54, modular = 39, architectural = 14, radical = 13)	1.88	1.00			
IT Rework (incremental = 53, modular = 35, architectural = 11, radical = 21)	2.00	1.12			
Implementation horizon (months)	26.87	20.49			
Project scope (single area = 29, multiarea = 31, single area multifirm = 39, multiarea multifirm = 21)	2.43	1.04			
Anticipated Delay (no = 0, yes = 1)	0.475	0.50			

†Item was reverse coded.

6. Analysis and Results

6.1. Analysis

Principal components analysis was used to examine convergent and discriminant validity for our two multi-item constructs, Cooperative Planning and Uncertainty. The first two component eigenvalues were 6.961 and 4.217, respectively, with the next largest eigenvalue a low 0.851 indicating a two-component solution. This two-component solution explained 79.8% of the variance in the data set. The component loadings (after Varimax rotation) in Table 1 indicate both convergent and discriminant validity for our two multi-item constructs where Component 1 denotes Cooperative Planning and Component 2 represents Uncertainty. The primary factor loadings are over 0.80 for all items, and the secondary loadings are all under 0.25.

Table 1 also shows the descriptive statistics for our survey variables and items. The items that make up Cooperative Planning all have means slightly over 4.0 on the 7-point scale and standard deviations around 2.0. The items that make up Uncertainty have slightly lower means and similar standard deviations. On these measures, both sets of items are consistent. Our two measures of the duration of delay, Downstream Delay and Project Delay, and one of our controls, Implementation Horizon, are measured in months. The average Project Delay is just over six months, and Downstream Delay averages slightly over four months. On average, the projected Implementation Horizon was 27 months, with an actual completion time of 33.3 months. Project Scope was evenly split between projects confined to a single functional area and those spanning multiple functional areas (within or between firms). Almost half the projects had anticipated their most critical delay (Anticipated Delay).

Project managers and IT managers answered both types of rework questions and their responses were highly correlated (0.963 for the magnitude of Upstream Rework and 0.960 for the magnitude of Downstream Rework). Consequently, we used responses from the manager with the most expertise about the nature of each type of rework—project manager responses for Upstream Rework and IT

Table 2 **Cross-Tabulation for Upstream Rework and Downstream Rework**

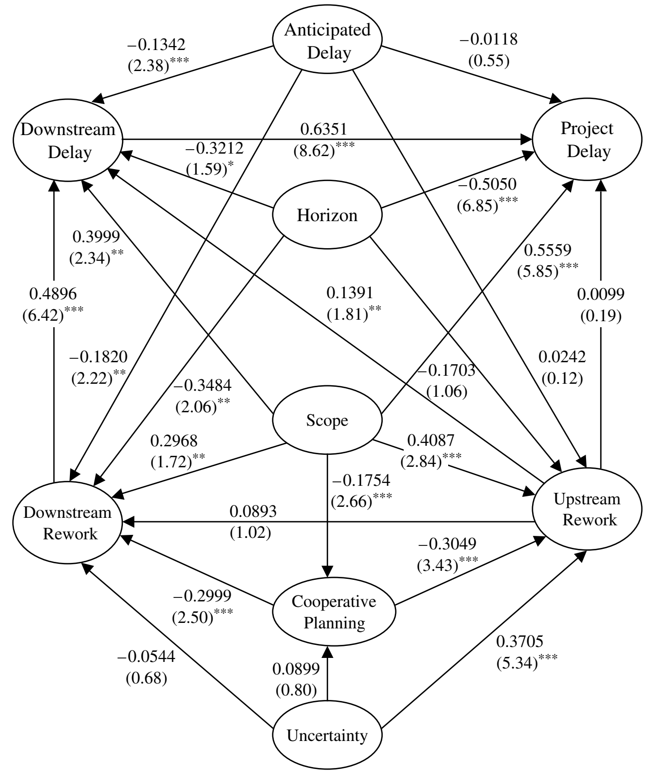
Magnitude of Downstream Rework	Magnitude of Upstream Rework				
	Incremental	Modular	Architectural	Radical	Total count
Incremental (% of total)	22 (18.3%)	29 (24.2%)	0 (0%)	2 (1.7%)	53 (44.2%)
Modular	17 (14.2%)	7 (5.8%)	6 (5.0%)	5 (4.2%)	35 (29.2%)
Architectural	7 (5.8%)	0 (0%)	2 (1.7%)	2 (1.7%)	11 (9.2%)
Radical	8 (6.7%)	3 (2.5%)	6 (5.0%)	4 (3.3%)	21 (17.5%)
Total Count	54 (45.0%)	39 (32.5%)	14 (11.7%)	13 (10.8%)	120 (100.0%)

manager responses for Downstream Rework. The distribution of rework across projects in Table 2 shows that incremental (upstream or downstream) rework was encountered most often (45% and 44%, respectively), with the number of projects decreasing as the magnitude of rework increased. However, only 18% of projects confined their rework to incremental change in both upstream and downstream design. Seventy-five percent of projects undergoing modular upstream rework confined their downstream rework to incremental or modular design change. Of the 14 projects that encountered architectural upstream rework, 12 were split between modular and radical downstream rework. Of the 13 projects experiencing radical upstream rework, the corresponding downstream rework was nearly evenly distributed across rework categories. This indicates our scales yield measures that are consistent with our expectations (see Safoutin 2003) of the magnitude of rework and provide a foundation for validity.

Our analysis uses PLS implemented on the PLS-Graph software (Chin 2001) to estimate the relationships between the latent variables that measure our constructs. In this analysis, our two main explanatory latent variables, Cooperative Planning and Uncertainty, are each measured with a set of items, and the remaining latent variables are single-item measures. PLS is a predictive technique that, as compared with multiple regression using factor scores from a factor analysis of the multiple items, also uses the variance in the items to predict the relationship between one latent variable and another. The relationships between latent variables that are single-item measures are the same as least squares regression. The advantage of PLS as compared to structural equation modeling is sample size: because PLS does not model the measurement error associated with each item, fewer parameters are estimated and a smaller sample size is needed. All items entered into the PLS analysis were standardized to zero mean and unit variance.

The PLS model representing our research model is provided in Figure 3. The numbers on the paths represent the inner-model's path coefficients—that is, the relationships between our latent variables. Both the path coefficients representing the mean of the

Figure 3 **Results Model**



Note. Significance: 0.1*, 0.05**, 0.01***.

resamples and the t-statistics in parentheses are generated from a bootstrap resample of 200. Resamples of 200 tend to provide reasonable and stable standard error estimates (Chin 2001). With our sample size and degrees of freedom, the t-distribution is close to Normal. The outer model's item loadings, that is, the loadings between the items and the latent variables, along with the composite reliability for our two multi-item latent variables—Cooperative Planning and Uncertainty—are provided in Table 1. As we can see from Table 1, each of the items representing Cooperative Planning loads positively and strongly on the latent variable. Only one loading is lower than 0.8 (0.788), and one third of the loadings are over 0.9. The composite reliability of these items is a very strong 0.965. Similarly, each of the items representing Uncertainty loads positively and strongly on the latent variable. All loadings are 0.89 and higher, and the composite reliability of these items is a very strong 0.964. These results show a strong and consistent relationship between each set of items and their latent variable.

6.2. Results

We begin with the results from Figure 3 and Table 3 that address our first research question, does greater cooperative planning reduce the magnitude of upstream and downstream rework, and does cooperative planning mediate the relationship

Table 3 PLS Results Mean of Subsamples (t-Statistic) and Sensitivity Analysis with Direction Change

	Model			
	Upstream Rework → Downstream Rework		Downstream Rework → Upstream Rework	
Path	With Cooperative Planning	Without Cooperative Planning	With Cooperative Planning	Without Cooperative Planning
Upstream Rework and				
Downstream Rework	0.0893 (1.02)	0.1923 (2.28)**		
Cooperative Planning	−0.3049 (3.43)***		−0.2685 (2.78)***	
Uncertainty	0.3705 (5.34)***	0.3550 (5.20)***	0.3640 (4.66)***	0.3659 (4.77)***
Scope	0.4087 (2.84)***	0.4281 (2.72)***	0.3872 (2.68)***	0.4348 (2.98)***
Horizon	−0.1703 (1.06)	−0.1285 (0.73)	−0.1345 (0.83)	−0.1407 (0.81)
Anticipated delay	0.0242 (0.12)	0.0405 (0.25)	0.0297 (0.39)	0.0323 (0.25)
Downstream Rework and				
Upstream Rework			0.0911 (1.13)	0.1866 (2.57)***
Cooperative Planning	−0.2999 (2.50)***		−0.3141 (2.90)***	
Uncertainty	−0.0544 (0.68)	−0.0503 (0.39)	−0.0256 (0.21)	−0.0457 (0.46)
Scope	0.2968 (1.72)**	0.4315 (2.49)***	0.3265 (2.02)**	0.4244 (2.42)***
Horizon	−0.3484 (2.06)**	−0.4259 (2.42)***	−0.3653 (2.25)**	−0.4141 (2.24)**
Anticipated delay	−0.1820 (2.22)**	−0.2027 (2.49)***	−0.1784 (2.03)**	−0.2072 (2.70)***
Project delay and				
Upstream Rework	0.0099 (0.19)	0.0054 (0.19)	0.0133 (0.17)	0.0008 (0.19)
Downstream delay	0.6351 (8.62)***	0.6321 (8.98)***	0.6354 (7.71)***	0.6388 (8.21)***
Scope	0.5559 (5.85)***	0.5610 (5.40)***	0.5638 (4.83)***	0.5591 (5.40)***
Horizon	−0.5050 (6.85)***	−0.5133 (5.97)***	−0.5128 (5.72)***	−0.5125 (6.11)***
Anticipated delay	−0.0118 (0.55)	−0.0135 (0.58)	−0.0113 (0.54)	−0.0138 (0.56)
Downstream delay and				
Downstream Rework	0.4896 (6.42)***	0.4846 (5.88)***	0.4946 (5.92)***	0.4847 (6.18)***
Upstream Rework	0.1391 (1.81)**	0.1316 (1.94)**	0.1333 (1.85)**	0.1410 (1.95)**
Scope	0.3999 (2.34)**	0.4043 (2.37)***	0.3902 (2.20)**	0.3933 (2.41)***
Horizon	−0.3212 (1.59)*	−0.3149 (1.63)*	−0.2992 (1.48)*	−0.0366 (1.59)*
Anticipated delay	−0.1342 (2.38)***	−0.1381 (2.31)**	−0.1349 (2.37)**	−0.1441 (2.35)**
Cooperative Planning and				
Uncertainty	0.0899 (0.80)		0.0926 (0.78)	
Scope	−0.1754 (2.66)***		−0.1802 (2.48)***	

Note. Significance: 0.1*, 0.05**, 0.01***.

between upstream and downstream rework. Figure 3 shows a significant and inverse relationship between the amount of Cooperative Planning and the magnitude of both Upstream and Downstream Rework. The first two columns of Table 3 show that Cooperative Planning mediates the relationship between Upstream and Downstream Rework: In the presence of Cooperative Planning, the path directly from Upstream Rework to Downstream Rework is not significant, but when Cooperative Planning is removed the same path becomes significant. Thus, our first research question is answered affirmatively—Cooperative Planning reduces Upstream Rework and reduces Downstream Rework, and the relationship between Upstream Rework and Downstream Rework is mediated by Cooperative Planning.

Examining the results from Figure 3 that address our second research question, does greater Uncertainty increase the magnitude of rework in upstream and downstream operations, we find only partial support. Increased Uncertainty significantly increases Upstream Rework so that there is a significant relationship between experience with the design and the magnitude of upstream rework. However, Uncertainty does not significantly affect the magnitude of Downstream Rework. Moreover, Uncertainty does not significantly affect the amount of Cooperative Planning. Therefore, the effect of uncertainty on upstream rework does not carry to downstream rework.

Project Scope is a significant control whereby greater Project Scope significantly increases the magnitude of both Upstream and Downstream Rework, and the duration of Downstream and Project Delay. Thus, complexity and rework, and complexity and delay, are positively related both upstream and downstream. Project Scope significantly reduces the need for Cooperative Planning, consistent with more complex projects requiring loosely coupled plans. A longer Implementation Horizon significantly reduces the magnitude of Downstream Rework and the duration of Project Delay. However, a longer Implementation Horizon does not significantly affect the magnitude of Upstream Rework or the duration of Downstream Delay. Anticipated Delay is a significant control as anticipating the most critical delay in the project reduces the magnitude of Downstream Rework and the duration of Downstream Delay.

Our third research question, does the magnitude of rework affect the duration of project delay, is embedded in several paths. Studying the path between Upstream Rework and Project Delay, we find that Upstream Rework does not significantly affect the duration of Project Delay. In contrast, Downstream Rework significantly increases the duration of Downstream Delay, and in turn, Downstream Delay significantly increases Project Delay. Moreover, Upstream Rework significantly increases Downstream Delay directly. Therefore, the magnitude of downstream rework affects the duration of project delay, as does the indirect effect of upstream rework, through downstream delay. However, the magnitude of upstream rework does not directly affect project delay.

We examined the sensitivity of our PLS results to changes in our model. First, we checked the sensitivity of our results to a removal of the direct path between Upstream Rework and Downstream Rework, a path that was insignificant in Figure 3. We removed this path to eliminate any confound with the relationships between our two main variables of interest, Cooperative Planning and Uncertainty, and the two types of rework. We found no differences in the significance of any paths in the model, and there was almost no change in the path coefficients. Next, we reversed the direction of the path between Upstream Rework and Downstream Rework, shown in the last two columns of Table 3. As with the original model, this path is insignificant in the presence of the mediating variable (Cooperative Planning), and is significant without the mediating variable indicating interdependence between the rework variables. The significance and signs of the remaining paths in the model are not qualitatively different from the original model. We also examined the sensitivity of our PLS results to a change in our measure of Project Scope, grouping the two middle measures of our Project Scope scale into one. The only significant change from our original model was that the path between Project Scope and Upstream Rework became insignificant. Thus, the magnitude of upstream rework is sensitive to whether the project crosses firm boundaries or spans multiple functions.

7. Discussion and Conclusion

Our empirical results can be summarized as follows. Consistent with the literature, greater cooperative planning in the form of strategy coupling and cross-functional involvement significantly decreases the magnitude of both upstream and downstream rework: by understanding each other's limitations and needs the two stages can better handle exceptions. In addition, cooperative planning mediates the relationship between upstream and downstream rework. Thus, increased effort in cooperative planning up front can pay off in reducing both upstream and downstream rework, and the relationship between upstream and downstream rework is through the amount of cooperative planning. Our interview data indicates that tight strategy coupling requires greater cross-functional participation in the planning process than loose strategy coupling, and early uncertainty resolution depends on the level of cross-functional participation. Tight strategy coupling involves a comprehensive, systematic analysis of the task environment that raises issues of BP-IT fit and allows for the extensive coordination of upstream (BP) requirements and downstream (IT) capabilities in formulating a blueprint for design. The earlier a project team can alleviate this uncertainty, the more predictable the upstream-downstream relationship, the more precise and stable the preliminary information, mitigating the magnitude of rework. In contrast, less cooperative planning in the form of loose strategy coupling is less effective in mitigating rework because of its reliance on coordination by mutual adjustment during implementation, rather than joint planning during pre-communication.

Also consistent with the literature, greater uncertainty from a lack of relevant firm or industry experience with related designs (fit novelty) significantly increases the magnitude of upstream rework. However, uncertainty does not affect the magnitude of downstream rework or the amount of cooperative planning. Thus, downstream activities can be isolated from some of the uncertainty associated with fit novelty. For example, in one of our cases, a hospital sought productivity gains by redesigning its clinical processes (upstream operations) around advances in IT (downstream operations)—specifically, bedside terminals. Bedside terminals allowed clinical personnel to capture information at its source, in the patient's room while providing care. Having little experience with clinical process redesign, significant upstream rework was needed to adapt to the bedside terminals, while little rework occurred downstream with the IT platform. Upstream rework occurred because physicians refused to use the terminals as they felt "trapped" in the patient's room while recording their clinical notes. Physicians maintained their original workflow patterns while nurses altered their routines multiple times until they arrived at an acceptable pattern of work activities (e.g., medication rounds and treatments were no longer performed sequentially, rather, intermittently). Thus, inexperience with clinical process redesign resulted in major upstream rework and little downstream rework for the IT department—showing how downstream work can be isolated from some of the uncertainty if downstream technology is one of the drivers of the project.

This situation supports the set-based approach to preliminary information exchange outlined by Terwiesch et al. (2002). Downstream activity could be isolated from upstream uncertainty because there was little ambiguity about the technology-process dependencies and the clinical information requirements were stable. Some information instability surrounded the information's mode of entry into the system that introduced uncertainty in clinical process design, but that instability did not affect IT platform design. Thus, the downstream IT department was able to isolate itself from upstream uncertainty. Our interview data further indicates that IT design consistently follows from BP design and corporate goals. The lack of experience with the design only affects IT development rework through uncertainty in BP design. Our interview data further indicates that IT design consistently follows from BP design and corporate goals. The lack of experience with the design only affects IT development rework through uncertainty in BP design. This finding is consistent with recent research on technology adaptation and IT-enabled change (Mitchell and Zmud 2006).

In our controls, we found that complexity in the form of Project Scope significantly affects the magnitude of both upstream and downstream rework as well as downstream and project delays. Our interview data reveals that projects spanning functional areas and multiple firms have greater system interdependencies that in turn increase design complexity. In addition, we found that project scope and cooperative planning are inversely related. When projects span functional areas and multiple firms, upstream and downstream strategies are loosely coupled to accommodate the dynamic adjustments needed as the project unfolds to resolve ambiguities in design. Therefore, project scope affects rework both directly, and indirectly through strategy coupling. This latter effect may confound the relationship between uncertainty and cooperative planning, a relationship we found was not significant, as managers may choose the level of cooperative planning based on complexity rather than on uncertainty. Our other controls were also significant. A longer Implementation Horizon (related to better forecasting) significantly reduces the magnitude of downstream rework and shortens project delays, but does not affect the magnitude of upstream rework or downstream delay. If the most critical delay is anticipated once the project is underway, then downstream rework and downstream delay are reduced, but whether the most critical delay is anticipated does not affect upstream rework or delays.

As with any empirical study, our study is limited to the population in which these results can be generalized. Our context was one of BP redesign and the design of IT to support the BP redesign. As such, the context was one where the upstream operation (BP design) and the downstream operation (IT development) were highly interdependent. This high level of interdependence increases the risks of rework that result from concurrent design. Our context was also characterized by applications of IT, and by large organizations facing extensive regulation. These characteristics create complexity in the design tasks, resulting in tasks that may not reflect the settings faced by other organizations. Finally, our measure of uncertainty is restricted to fit novelty, and thus the uncertainty we model is mainly foreseeable.

The implications of our results are that the magnitude of downstream rework in concurrent design is under managerial control. Of our two constructs, uncertainty and cooperative planning, only cooperative planning significantly affects the magnitude of downstream rework and cooperative planning is under managerial control. Our statistical controls, complexity, size, and whether the most critical delay is anticipated before the project is underway, represented by project scope, implementation horizon, and anticipated delay, respectively, also affect the magnitude of downstream rework (additionally through cooperative planning in the case of project scope) and are also under managerial control.

However, the magnitude of upstream rework is not completely under managerial control—our measure of uncertainty significantly increases the magnitude of upstream rework, and this type of uncertainty cannot be resolved because it depends on prior experience. Nonetheless, the magnitude of upstream rework is under some measure of managerial control—cooperative planning and complexity both significantly affect the magnitude of upstream rework. Most surprisingly, the duration of Project Delay is only affected by the magnitude of upstream and downstream rework through downstream schedule slippage, but not directly by the magnitude of upstream rework. Therefore, the duration of project delay appears to be under managerial control because project delays are not directly affected by uncertainty that acts only through the magnitude of upstream rework.

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Appendix. Survey Instruments

Phone Interview Guide

What is the most recent redesign project you've implemented (project name)?
What were the project's goals?
What is the project's scope: (1) isolated to a functional area, (2) spans a single functional area across multiple firms, (3) spans multiple functional areas within the firm, (4) spans multiple functional areas across multiple firms.
Describe the process before the redesign project was implemented.
Describe the intended work process.
Describe the final work process (if it differs from the intended process).
When did this project start?
What was the initial scheduled completion date? What was the actual completion date?
What was the most critical Project Delay experienced?
How long did this delay the project? Was this delay anticipated?

Using the scale provided, please indicate the extent to which you agree or disagree with the following statements as they pertain to the redesign project.

Uncertainty items—Project manager	Strongly disagree			Agree			Strongly agree
PM1. The redesigned process chosen was a de facto industry standard†	1	2	3	4	5	6	7
PM2. The redesigned process was unique to this company, no one else is using it	1	2	3	4	5	6	7
PM3. This design was adopted because of its proven usefulness in the industry†	1	2	3	4	5	6	7
PM4. The redesigned process was a major departure from previous operations	1	2	3	4	5	6	7
PM5. The redesigned process is similar to process designs used in other areas of the company†	1	2	3	4	5	6	7

†Item was reverse coded.

Upstream Rework (design change)

Please indicate the response that best describes the extent to which the initial process design and intended IT platform design was changed to facilitate project completion.

1. Minor changes were required to the initial redesigned process. New skills or additional training to handle material and information flows were generally not required.
2. Major changes were required in one or more of the tasks embedded in the initial redesigned process, however, the flow of materials or information was not altered. New skills were required to accomplish the modified tasks.
3. Major changes were required in the flow of materials or information moving through the initial redesigned process, however, the tasks embedded in the intended design were not altered. Employees had to be educated regarding the new process flows.
4. Major changes were required in both the tasks embedded in the redesigned process and associated flows of material or information. New skills were required to accomplish the modified tasks and employees had to be educated regarding new process flows.

Note: *Project Managers were also asked about Downstream Rework and IT managers were asked about Upstream Rework. Their responses were highly correlated on each question.*

Additional questions asked of the IT manager.

Project title:
When did the IT portion of the redesign project start?
What is the schedule completion date for the IT changes?
What was the most critical IT-related delay experienced?
How long did this delay the project?

Using the scale provided, please indicate the extent to which you agree or disagree with the following statements as they pertain to the redesign project.

Coordination items—IT manager	Strongly disagree			Agree			Strongly agree
ITM1. The company has an IT strategic plan	1	2	3	4	5	6	7
ITM2. The IT strategy supports the redesign project's strategy	1	2	3	4	5	6	7
ITM3. Business unit managers are involved in IT planning	1	2	3	4	5	6	7

Coordination items—IT manager	Strongly disagree			Agree			Strongly agree
ITM4. IT specialists were consulted prior to implementing the redesign project	1	2	3	4	5	6	7
ITM5. The goals of the redesign project were made clear to the IS staff	1	2	3	4	5	6	7
ITM6. IT capabilities were recognized and exploited by the new process design	1	2	3	4	5	6	7
ITM7. The information and IT needs of the redesign project were considered when formulating the IT plan	1	2	3	4	5	6	7
ITM8. An assessment of IT strengths and limitations was utilized by the redesign planners	1	2	3	4	5	6	7
ITM9. An assessment was made of relevant IT trends prior to implementing the redesign project	1	2	3	4	5	6	7

Downstream Rework (design change)
Please indicate the response that best describes the extent to which the initial process design and intended IT platform design was changed to facilitate project completion.

1. Minor changes were required in the IT platform; new skills or additional training on the part of information systems personnel were not required.
2. Major changes were required in the components of the IT platform (hardware, software, data) *without* changing the platform's basic configuration. Components were changed in such a way that new knowledge was required on the part of information systems personnel to implement the change.
3. Major changes were required in the IT platform's configuration *without* significantly altering the components themselves. New skills and policies were needed to implement the change.
4. Major changes were required in one or more of the components making up the IT platform as well as the relationships among components that altered the network's basic configuration.

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