Capability Traps and Self-Confirming Attribution Errors in the Dynamics of Process Improvement

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To better understand the factors that support or inhibit internally focused change, we conducted an inductive study of one firm's attempt to improve two of its core business processes. Our data suggest that the critical determinants of success in efforts to learn and improve are the interactions between managers' attributions about the cause of poor organizational performance and the physical structure of the workplace, particularly delays between investing in improvement and recognizing the rewards. Building on this observation, we propose a dynamic model capturing the mutual evolution of those attributions, managers' and workers' actions, and the production technology. We use the model to show how managers' beliefs about those who work for them, workers' beliefs about those who manage them, and the physical structure of the environment can coevolve to yield an organization characterized by conflict, mistrust, and control structures that prevent useful change of any type.●

Few ideas are more central to organizational theory than the notion that with time and experience organizations improve their existing capabilities. Theories ranging from those of March and colleagues (e.g., Cyert and March, 1992; March and Simon, 1993) to population ecology (Hannan and Freeman, 1984) and punctuated equilibrium (Tushman and Romanelli, 1985) rest on the premise that learning by doing and imitation enable organizations to improve the execution of their core tasks and processes. Studies show that organizations often experience sustained periods of improvement driven by both learning by doing and knowledge transferred from others (Argote, 1999). Yet a closer look suggests that the processes through which organizations achieve internally focused change are more complex and problematic than the literature suggests. Recent studies on total quality management (TQM), for example, have found that firms with serious TQM programs outperform their competitors (Hendricks and Singhal, 1996; Easton and Jarrell, 1998). Yet most efforts to implement TQM fail. Easton and Jarrell (1998) found fewer than 10 percent of the *Fortune* 1000 had well-developed TQM programs, and Rigby (2001) reported that between 1993 and 1999, TQM fell from the third most commonly used business tool to 14th in the U.S. TQM's efficacy is undeniable, but, paradoxically, it remains little used.

The phenomenon of useful innovations that go unused is not limited to TQM. For example, although the utility of various human resource practices has been carefully documented (Pfeffer, 1998), Pfeffer and Sutton (2000) reported that they remain infrequently employed. Similarly, Wheelwright and Clark (1995) lamented the poor implementation record of best practices for product development. The inability of many organizations to use the knowledge embodied in administrative innovations like TQM and high-performance human resource and product development practices is a central issue facing organizational theorists (Pfeffer, 1997: 202–203).

The failure of organizations to capitalize on the opportunities presented by TQM and other administrative innovations is also one manifestation of a broader challenge facing organiza-

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tion theory. While firms often experience extended periods of improvement, learning rates vary significantly both within and across firms (Argote, 1999); existing theory offers little to explain why. Without an operational understanding of why learning rates differ, theories built on the assumption that organizations make regular gains in existing capabilities rest on shaky ground.

Though the reasons organizations succeed or fail to implement administrative advances remain unclear, the literature offers at least three threads from which theory can be woven. First are the prescriptive writings of the creators of improvement techniques (e.g., Crosby, 1979; Ishikawa, 1985; Deming, 1986; Juran, 1995). TQM is important in this respect because it provides both technical tools (e.g., statistical process control) and behavioral and organizational precepts (e.g., Deming's Fourteen Points). These prescriptive writings do not, however, contain underlying theory detailing why these practices are necessary or how results might differ if they are not followed. A second strand, scholarly analyses of TQM, helps fill this void. Hackman and Wageman (1995) identified a number of gaps between TQM practice and organizational and psychological theory, and since then, TQM has been interpreted from a variety of perspectives, including sociology (Zbaracki, 1998), institutional theory (Westphal, Gulati, and Shortell, 1997), strategic management (Powell, 1995), economics (Wruck and Jensen, 1994; Repenning, 2000), contingency theory (Sitkin, Sutcliffe, and Schroeder, 1994), and sensemaking (Weick, 2000). Though these studies have added to our understanding of programs like TQM, much remains unexplained. The situation is similar for other innovations (Klein and Sorra, 1996; Pfeffer, 1997). Finally, there is the growing literature on the more general processes of technology implementation. Following Giddens (1984), these studies highlight the recursive relationships and mutual causal links among technology, institutional structures, beliefs, and behavior (e.g., Barley, 1986; Orlikowski, 1992). Similarly, recent field studies explicitly considering feedback confirm the complexity of the dynamics that emerge from efforts to implement improvement techniques (Sterman, Repenning, and Kofman, 1997; Keating and Oliva, 2000; Repenning, 2002).

Taken together, these three strands suggest both that such techniques do work and that, despite their documented benefits, we should not be surprised that efforts to implement such innovations sometimes fail—new technologies often produce distinctly different outcomes when introduced into different contexts (e.g., Barley, 1986). Despite these contributions, however, the paradox posed by useful but unused innovations remains. The structures, processes, and feedbacks that influence whether an organization learns or stagnates, whether a promising improvement program is adopted or rejected, remain largely unknown.

In this paper we take some steps toward such a theory through the inductive study of process-focused improvement. Process-focused improvement efforts present a useful context in which to study the micro-processes that impede or facilitate competence-enhancing change for several reasons.

Most such programs focus on existing capabilities and, although they do not entail radical changes to the firm's strategic position, often fail (Dean and Bowen, 1994; Easton and Jarrell, 1998), thus providing an entry point into understanding the forces that limit success. Improvement programs are also frequently attempted (and studied) and are thus of interest in their own right. To use attempts at process-focused improvement as a window onto the dynamics of incremental change, we conducted two original field studies in a division of a major U.S. automaker that designs and manufactures electronic components.

METHODS

At the outset, we assembled a team of people working in the division to assist the first author in performing the field research. The team included a division vice president, people who had (or previously had) line responsibility in plants or product development, internal consultants, and division staff; most had participated in numerous improvement and change initiatives. Following a polar types research design (Eisenhardt, 1989: 537), the team began by identifying initiatives that were either dramatic successes or failures, with the expectation that their comparison would help identify those processes that prevent competence-enhancing change. We also sought initiatives that were sufficiently large in size and scope that they had the potential to significantly affect organizing practice. Discussions with team members led to two initiatives: a Manufacturing Cycle Time reduction program (the MCT initiative) and a program focused on improving the Product Development Process (the PDP initiative).[1] The two initiatives offered a unique opportunity to study process improvement for several reasons. First, they provided a stark contrast in results: MCT was a major success, leading to a twenty-fold reduction in manufacturing cycle time and savings of hundreds of millions of dollars, while PDP failed to achieve most of its objectives. Second, though less successful, PDP conformed better to conventional wisdom concerning successful organizational change. Third, the same executive (the general manager of the division) led both initiatives, providing an opportunity to control for senior leadership and management style.

Data Collection

Both initiatives were recently completed at the time the study was begun, and data on them were collected primarily through semi-structured interviews. Sixty-four formal interviews were conducted with fifty-six different people. The formal interviews were supplemented with numerous follow-up conversations on the telephone, via e-mail, and in the hallways. Interview subjects included both a hierarchically stratified sample of the participants in each initiative and a representative sample of those whose work was influenced by them. For MCT, interviewees included the executive who launched the initiative, executives whose functions were influenced by it, the manager charged with promoting MCT, his entire staff, and representatives of the various support groups that assisted with the effort. The research also included studies of two plants that participated in MCT, the pilot

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[1] We initially included a third effort in our design, an internal-supplier certification initiative patterned after the Baldridge Award. After initial interviews and data collection, however, the initiative was dropped from the study when it became clear that it was more focused on documentation than actual process improvement. The results of the study are reported in Johnsson (1996).

site and a later adopter. At both, the researcher interviewed the plant manager during the program, members of the staff charged with propagating MCT, line managers whose areas adopted the MCT techniques, and machine operators who used them. For the PDP study, the list again included the executive who launched the effort, executives whose areas were influenced by it, members of the team that designed the initiative, and members of the groups charged with supporting it. We also studied two product programs: the alpha pilot, the first to follow the PDP protocol, and a beta pilot, part of the second wave of programs using PDP. Interviewees included the chief engineers overseeing each pilot program, the managers leading the efforts, and participating engineers.

Interviews lasted between 45 and 90 minutes and were taped. Interviewees were presented with a one-page outline of the topics to be covered. Informants began by describing their background and history with the organization. They were then asked to give a detailed account of their experience with the initiative and to assess its successes and failures. Finally, they were asked to speculate on what they would do differently were they to participate in a similar initiative again. As soon as practically possible (usually the same evening), the interviewer listened to the tape, reviewed his interview notes, and wrote a detailed summary of the interview and his initial reactions. Later, the interview tapes were transcribed.

To reduce hindsight and selection bias, we also observed practice and collected archival data. We collected a wide range of pamphlets, newsletters, instructional books, and video and audiotapes used in the initiatives. For MCT, extensive data on actual cycle times, product quality, productivity, etc., were also available. Fewer data were available on PDP. By observing actual development and manufacturing practice, we were able to test claims about how each initiative influenced day-to-day work. The quantitative, archival, and observational data were used to triangulate the emerging theory.

Data Analysis

We began our data analysis with traditional methods for inductive fieldwork (e.g., Miles and Huberman, 1984). The first author read all the interview transcripts, notes, and post-interview summaries and wrote two detailed cases describing the initiatives.[2] All interviewees were then given the cases to review their quotations for accuracy. Changes were not permitted unless there was a factual dispute that could be resolved with additional data. Case reviews often led interviewees to provide additional data. Allowing the participants in the study to review the cases helped offset some of the bias normally associated with retrospective interviews. While the recollection of a given participant typically informed only a small portion of the overall narrative, interviewees read and reviewed the entire case, often identifying issues that had not arisen in their original interview. When possible, challenges to the case narratives were resolved using the archival data or with additional interviews. The research team

[2] The case studies can be downloaded at http://web.mit.edu/nelsonr/www or can be obtained from the authors.

also reviewed the cases, identifying gaps in the narrative and suggesting data to be collected.

We next turned to developing a theory to explain the evolution of each initiative. We used the causal loop diagramming method common in system dynamics (e.g., Sterman, 2000; see also Weick, 1979) and recently applied in organization theory (e.g., Sastry, 1997; Repenning, 2002; Perlow, Okhuysen, and Repenning, 2002). The process begins with the selection of patterns of interest from the initial data analysis (e.g., early use of an improvement method followed by abandonment) and then continues with the iterative development of categories into which observations can be coded, as in Glaser and Strauss (1967). The variables and causal links among them emerging from this analysis form the feedback processes that generate the dynamics of the system. We began by developing causal diagrams describing particular episodes in each initiative. We then integrated these episode-specific diagrams into a unified framework explaining both successes and failures. The result is a single set of feedback processes capable of generating the multiple patterns of implementation activity we observed. During this phase, we often returned to the data to check for and resolve any anomalies or contradictions. We regularly reviewed our results with members of the research team, who often suggested additions and clarifications.

As our model emerged, we reviewed each link in the causal map to assess whether the relationship was supported by existing studies. The operations management and quality literatures were helpful in specifying those links capturing the physics of the production process. The behavioral decision-making and social psychology literatures were helpful in specifying the behavior of those working in the physical production system. These methods helped ensure that our model was grounded in the field data and consistent with principles of operations and quality management, organization theory, and the experimental literature on human decision making.

OVERVIEW OF THE TWO INITIATIVES

Manufacturing Cycle Time (MCT)

Prior to the MCT effort, the division's plants were operated like those of many firms whose business requires substantial capital investment and labor expense. Line supervisors were charged with keeping each piece of equipment and each worker fully utilized. The performance measurement and evaluation system emphasized labor productivity (roughly, the number of units produced per person per day) and gave supervisors a strong incentive to keep high levels of work-in-process (WIP) inventory to ensure that breakdowns and quality problems at upstream machines did not force downstream machines to shut down. Consequently, a large portion of each plant's floor space was dedicated to holding WIP inventory.

High WIP inventory levels hobbled plant performance in several ways. WIP inventory was expensive, it delayed quality feedback—a machine could produce many defective parts before these defects would be discovered by downstream operations—and it increased cycle time, making it difficult for plants to change production on short notice without costly expediting. Many materials managers recognized these problems, but every time they cut inventory, part shortages idled machines, causing plant managers to demand that the inventory be added back. High WIP inventory levels and expediting were adaptations through which the system had evolved to accommodate quality and reliability problems.

A new general manufacturing manager (GM), recently recruited from a leading electronics firm, launched the MCT initiative. He described the genesis of the effort, "We analyzed [for a sample product] the time elapsed between when a part came in the back dock until the time it left the shop floor. . . . We found out it took 18 days to make the product and we were adding value to the product 0.5 percent of the time." Building on this analysis, the GM targeted the time products spent between operations instead of the conventional focus on reducing the time parts spent on a particular machine. To launch the program, the GM spent much of his time visiting the division's plants. "I wanted to show them examples," he recalled, ". . . I might look at the shipping labels in the warehouse. If it was May, I'd usually find parts that had been received the previous August, and I would ask, 'if you aren't using this stuff until May, why has it been sitting here since last August?'" These trips stimulated interest in cycle-time reduction. Early efforts at the plants focused on developing metrics for cycle time and value-added percentage. Improvement began almost immediately. In the first year, cycle time at the pilot plant fell more than 50 percent.

In the second year, the GM created a four-person group at headquarters to promote MCT division-wide. They began by requiring each plant to calculate and report a metric called manufacturing cycle efficiency (MCE), defined as the ratio of value-add time (time in which a function or feature was being added to the product) to total manufacturing cycle time. Early results were not encouraging—the value-added percentages were often less than 1 percent—but the process proved valuable. A staff member recalled, ". . . you had to walk through the shop floor and ask the question, 'Is this value added?' for every step in the process. . . . After calculating MCE, we . . . knew where value was being added, and, more importantly, where value was not being added." Armed with this knowledge, the division cut its cycle time from fifteen to less than five days.

Two years into the initiative, with the MCE analysis well underway in most facilities, the corporate staff focused on shop-floor management as the next opportunity for improvement. The corporate group chose the Theory of Constraints (TOC) method offered by the Goldratt Institute (Goldratt and Cox, 1986). Within six months almost every manufacturing engineer and supervisor had participated in a two-day TOC class. The following year, they trained almost every operator and material handler in the division. TOC became widely accepted and continues to play an important role in managing the plants.

The MCT effort was a great success. Between 1988 and 1995, the average manufacturing cycle time fell from approximately fifteen days to less than one day. Product quality improved, and revenue, profit, and cash flow all increased significantly. Many facilities are now able to change their production schedule on a daily basis, something that was impossible before MCT. Finally, the reduction in WIP inventory freed enough floor space in existing plants that two of five planned new facilities were not needed, saving hundreds of millions in capital expenditures.

Product Development Process (PDP)

Following the success of MCT, the general manufacturing manager was promoted. As head of the division, he was now also responsible for product development. He launched the PDP initiative by forming a dedicated task force with the following charge: "We need a development process that is fast, is the best in the industry, and it needs to increase throughput by 50 percent in two years. And everyone must adhere to the same process." The task force included representatives from the major functions within the organization. Following standard practice, they hired a consultant, documented the current process, and compared that process with those used by other firms. PDP was not the first attempt to speed product development; previous programs, however, had met with mixed results. The PDP team consolidated two initiatives already underway, along with the benchmark results, to produce the new development process.

Three elements distinguished PDP from prior practice. First, PDP mandated a one-pass development process. Historically, projects were started with ambiguous customer requirements and often required many costly prototypes as specifications evolved. To combat this build-and-bust cycle, PDP mandated thorough documentation of customer requirements, which would then be frozen before detailed design began. Combined with extensive use of computer-aided design (CAD) tools, the task force hoped to develop new products with one physical prototype and little rework. Second, to propagate learning, PDP included the "bookshelf," a library of reusable technologies and subsystems. Engineers were expected to document the uses, capabilities, and limitations of all new technologies, then place them on the bookshelf for others to use. To complement the bookshelf, PDP also specified a "wall of innovation." New technologies often led to delays or quality problems. To prevent projects from proceeding too far with unproven technologies, the wall of innovation marked the point beyond which every component and technology in a design had to be proven, documented, and posted to the bookshelf. Third, PDP was designed to increase discipline. The process was divided into six major phases, and development teams were required to undergo "phase exit quality reviews" before proceeding from one phase to the next. The reviews, which were conducted by senior managers, required project teams to document their progress and conformance to objectives in detail. PDP also sought to increase accountability by requiring engineers to use project management software and Gantt charts between reviews.

Hoping to identify and correct problems in the new process, the design team tested PDP on a number of pilot projects, the first of which was a high-profile product critical to the corporation's image and financial success. If successful, the pilot projects could also be used to promote PDP throughout the organization. The pilots suffered, however, from inadequate support infrastructure. Engineers did not have computers powerful enough to use the new design software. Once new computers did arrive, the rest of the organization could not accept their output due to software incompatibility. Solving these problems and learning to use the new tools imposed a substantial burden on the already overworked engineers. One recalled, "We never had time to take the courses and get the equipment we needed to really make this stuff work. . . .It was really exhausting trying to learn how to use the tools and do the design at the same time." The first pilot project also used many new and unproven technologies. As the first test of the new process, the bookshelf of documented designs was nearly bare; consequently, engineers were not able to achieve the one-pass design dictated by PDP. Instead, much of the design was substantially reworked late in the development cycle, increasing stress on the project team.

To meet the project schedule, engineers working on the pilot projects abandoned much of PDP's methodology. One recalled, ". . . we crashed through the wall of innovation and never looked back." These problems sapped morale—every interviewee reported frustration with PDP. Many felt management had imposed the new process and then immediately gave them a time line that could not be accomplished using it. An engineer expressed a common sentiment: ". . . I believe PDP is a good process. Some day I'd really like to work on a project that actually follows it."

Assessing the success of the PDP initiative is difficult. The division and parent company have since undergone numerous reorganizations. Further, there is little quantitative data with which to evaluate it. The lack of data, caused by long cycle times for development projects, is a key feature of the feedback structure governing the success of the program, not just a problem for researchers. Lacking rapid feedback on results, people formed judgments about the effectiveness of PDP through personal experience, anecdote, and rumor. Despite the lack of hard data, many people developed strong feelings about the program's impact. The GM rated the effort a 50-percent success. The executive in charge believed they achieved 80 to 90 percent of their objectives for the use of new tools but less than 20 percent of their objectives for documentation of customer requirements, using project management, and developing a more rigorous and repeatable process. Members of the design team also believed the effort failed to achieve its goals but hoped it would provide a catalyst for future improvements. Among the engineers interviewed, not one believed the initiative had materially influenced his or her job.

Conflicting Objectives and Conflicting Attributions

Our initial analysis of the data revealed two findings. First, nearly all participants, in both manufacturing and development, described a trade-off between doing their "real" work and the improvement work required by the initiative (e.g., run experiments to reduce cycle time in MCT, or place designs on the bookshelf in PDP). A staff member recalled the system prior to MCT:

> In the minds of the [operations team leaders] they had to hit their pack counts. This meant if you were having a bad day and your yield had fallen . . . you had to run like crazy to hit your target. You could say, "You are making 20 percent garbage, stop the line and fix the problem," and they would say, "I can't hit my pack count without running like crazy."

Similarly, an engineer from a PDP pilot project explained the difficulty he experienced in trying to use the project management techniques required by the PDP process: ". . . [under PDP] none of our old tasks went away, so the new workload was all increase . . . in some cases your workload could have doubled . . . many times you were forced to choose between doing the physical design and doing the project and administrative work [and] you had to do the design work first." An engineer from a different pilot project was more blunt: "People had to do their normal work as well as keep track of the work plan. There just weren't enough hours in the day, and the work wasn't going to wait." While both reported lacking the time for the activities required by PDP, neither, like other interviewees, contested its benefits. As one said, "The tenets of PDP are good; using them is a different story."

Beyond highlighting the trade-off between long-run improvements and short-run production targets, interviewees also reported intense pressure to achieve production objectives, often feeling compelled to cut the time spent on improvement. Before MCT, supervisors and operators, afraid to miss throughput objectives, would not stop their machines to do preventive maintenance, fix problems, or run experiments. As one manager said, ". . . supervisors who missed their targets knew they were going to get 'beat up' by their managers." Similarly, product development engineers would not use project management software, learn CAD tools, or document their uses of new technology for fear of missing deadlines. As one engineer said, "The only thing they shoot you for around here is missing product launch. Everything else is negotiable."

We are not the first scholars to identify the trade-off between improving and working. It appears in previous studies of process improvement (e.g., Carroll, Sterman, and Marcus, 1997), has been the subject of formal, rational-actor models (e.g., Fine, 1986), and has become a staple of personal and business books (e.g., Covey, 1989; Senge, 1990). The interesting question for theory is why, despite ample evidence suggesting that improvement and learning are worth substantial investment, and the vast array of scholars and consultants who preach its virtues, do many people still grossly underinvest in such activities?

The second observation arose initially from the PDP effort. While the engineering staff reported conflicting objectives and having little time for improvement, senior managers attributed the failure of the initiative to lack of discipline among the engineers. The executive in charge of the PDP design team recalled the results of its initial assessment, ". . . we found . . . [the existing development process] was . . . poorly documented and poorly disciplined." Similarly, a chief engineer characterized his view of the process before PDP: "We went through a period [prior to PDP] where we had so little discipline that we really had the 'process du jour.' Get the job done and how you did it was up to you." Based on these assessments, the executive in charge declared that the prime objective of PDP was "to instill some rigor, repeatability, and discipline into the process." Despite their efforts, the leaders of PDP felt that they were not successful in achieving this objective and attributed the failure to the engineering staff. One chief engineer said, ". . . it was fair to say that a lot of engineers viewed [PDP] as a neat way to get some fancy tools and to hell with the process." Similarly, the leader of PDP recalled, "A lot of the engineers felt that . . . they should have spent all their time doing engineering, not filling out project worksheets. [PDP] was brushed off as bureaucratic."

Given the gap in the assessments of engineers and managers, we turned to the question of whether such a contrast existed in manufacturing prior to or during the MCT initiative. Operators and line supervisors highlighted the basic trade-off between improvement and meeting aggressive production objectives, but managers typically did not reveal much information about their pre-MCT assessments. They did, however, provide detailed information about the measurement and performance evaluation schemes used in the plants.

Before MCT, the plants operated under a tightly constraining measurement scheme, designed, in the words of one supervisor, ". . . [to] make sure every worker and every machine was busy all the time." Line supervisors were evaluated on their labor efficiency—roughly the number of units produced per person—on a daily basis, and performance was scrutinized by managers at the highest levels. It was not unusual for division vice presidents to focus on the performance of specific machines. The combination of tightly specified production targets and an incentive scheme that strongly discouraged missing those objectives had a predictable effect on behavior. As one operations manager recalled, ". . . supervisors would always hit their exact targets. If the goal was 200, they would pack [produce] 200, never 198, never 202."

Thus, the manufacturing environment before MCT was similar to that in product development. Employees in both areas faced a strong trade-off between doing their work and engaging in process improvement. The incentive and measurement schemes in both functions had evolved so that people did not feel that they could risk missing their objectives by participating in improvement. Managers evaluated machine operators on a daily basis and imposed severe penalties for low performance. Engineers were required to produce detailed documentation concerning their development activities. These observations turned our attention to the question of why the system evolved so that engineers and operators, despite feeling it was not the best thing to do, focused exclusively on their self-described "real work" and never invested in process improvement, while, at the same time, managers did not acknowledge the trade-off and, instead, felt that their attempts at improvement failed because the workers lacked discipline. The answer that emerged from our analysis is rooted in the ongoing interactions among the physical production technology, organizational structures and routines, and the mental models and behaviors of workers and managers. To develop our argument, we begin with a model that captures the basic physics of a production process and the options available to those who attempt to improve it.

A MODEL OF PROCESS IMPROVEMENT

The Physical Structure of Improvement

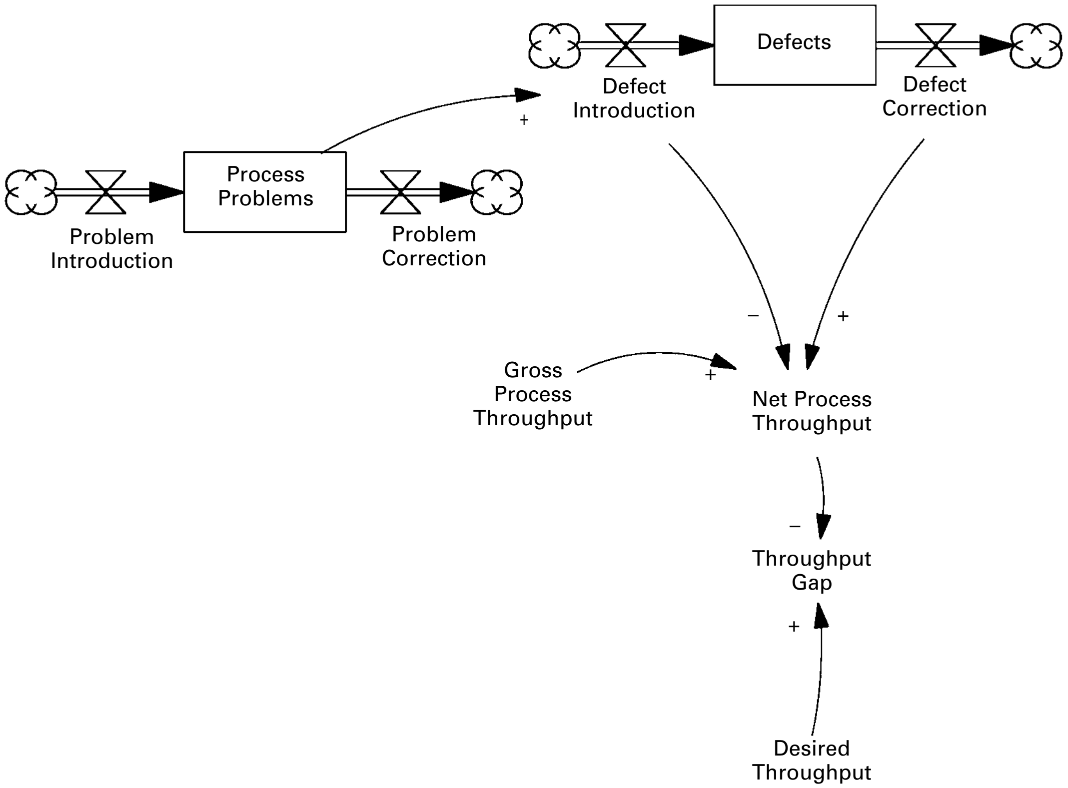
The first construct in our model is *net process throughput,* which is the rate at which inputs are successfully converted into outputs (e.g., saleable products manufactured per day or usable designs completed per month) and represents the "real work" of the organization. Net throughput is determined by three variables: *gross process throughput,* the total quantity of new work accomplished (e.g., widgets per day or designs per month); *defect introduction,* the flow of new work that is unusable because it was done incorrectly (e.g., defective widgets per day, flawed designs per month); and *defect correction,* the rate at which previously defective work receives additional attention and becomes usable. The term defect includes any undesirable outcome of a conversion process (Schneiderman, 1988). For example, products produced correctly but delivered late are defective if customers value timely delivery. Figure 1 shows these physical relationships in the form of a causal diagram.[3]

Figure 1 also shows the stock of *defects,* the accumulation of the rate at which defects are introduced less the rate at which defects are corrected. A stock, denoted by a rectangle, is the integration (accumulation) of its inflows less its outflows. Flows are denoted by straight arrows with valves. Stocks and flows complement feedback loops in representing the system's structure. Because they accumulate past actions, stocks give systems inertia, create delays, and provide systems with memory. Stock and flow structures are critical in creating dynamics: stocks characterize the states of the system upon which decisions are based; these decisions then change the rates of flow that alter the stocks, thereby closing the feedback loops in the system.

The rate of defect introduction is determined by the stock of *process problems*. In manufacturing, defects are often created by physical features of the machinery (e.g., a dull cutting tool) and will continue to be produced until machines are stopped and the defect-causing elements are eliminated. To capture this permanence, we draw on the distinction made in the quality movement between correcting defects that have already been produced and preventing them from occurring (Deming, 1986). We label the causes of defects process problems, which are also known as root causes (Ishikawa, 1985). Process problems are any features of the system, either physical or behavioral, that generate defects.

[3] Causal diagrams are not intended to provide a mathematical specification of the relationships, which may be linear or nonlinear and may include delays between cause and effect. Specifying a formal mathematical model is often the next step in testing the theories embodied in causal diagrams. Examples of formal feedback models of process quality and improvement programs include Sterman, Repenning, and Kofman (1997), Oliva and Sterman (2001), and Repenning (2002).

Figure 1. Determinants of process throughput.



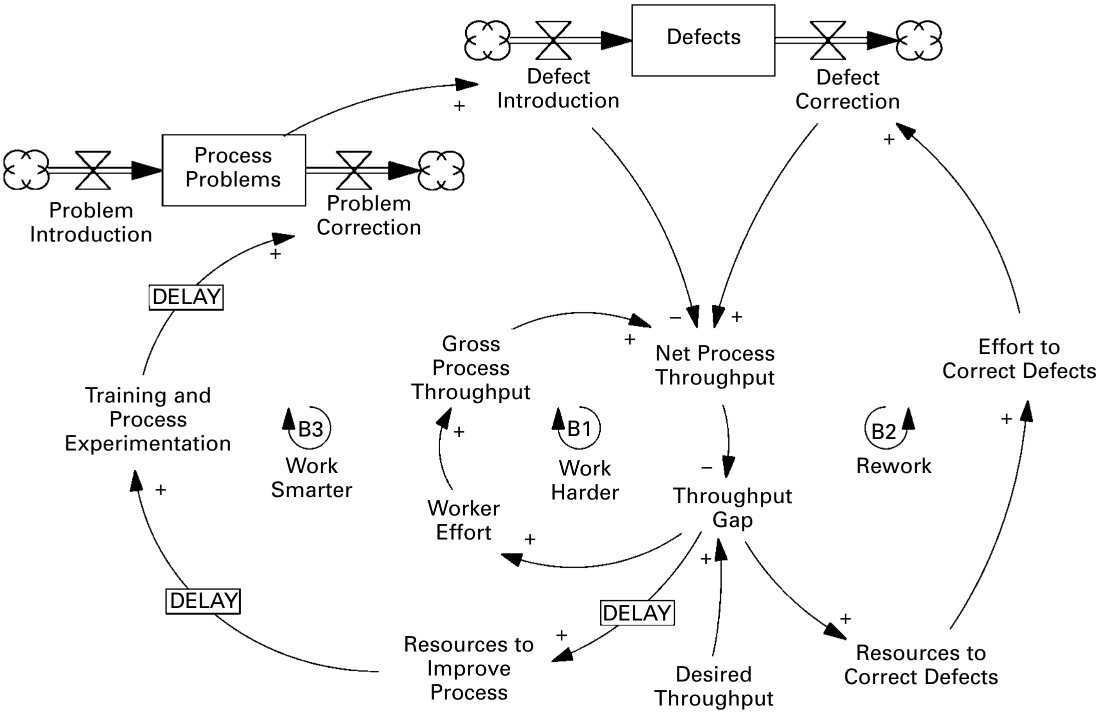
Note: Plus or minus at the arrow head indicates the polarity of the causal relationship: a plus sign denotes that an increase in the independent variable causes the dependent variable to increase, ceteris paribus (and a decrease causes a decrease); that is, $X \xrightarrow{+} Y \Leftrightarrow \partial Y/\partial X > 0$. Similarly, a minus sign indicates that an increase in the independent variable causes the dependent variable to decrease; that is, $X \xrightarrow{-} Y \Leftrightarrow \partial Y/\partial X < 0$. For example, net process throughput = gross process throughput – defect introduction + defect correction. Boxes represent stocks; arrows with valves represent flows. A stock is the accumulation of the difference between its inflows and outflows. Formally, $\text{defects}(t) = \int_t [\text{defect introduction}(s) - \text{defect correction}(s)]ds + \text{defects}(t_0)$ (see Sterman, 2000).

The stock of process problems is increased by *problem introduction* and reduced by *problem correction*. Process problems arise as equipment ages and wears and as changes in products, processes, or customer requirements create conflicts with existing routines, skills, or equipment. Learning and process improvement activity may lead to the identification and elimination of the root causes of defects, reducing the stock of process problems, decreasing the defect introduction rate, and improving net process throughput. Explicitly representing the key stocks in the system highlights the importance of distinguishing between defect correction and defect prevention (e.g., Deming, 1986). Because the stock of process problems determines the flow of defects, one process problem creates a continual inflow of defects, forever reducing net process throughput unless each and every defect is corrected. Conversely, eliminating a single process problem forever reduces the stream of defects. The challenge of process improvement lies in shifting attention from reducing the stock of defects to reducing the stock of process problems.

Responding to Throughput Pressure

Figure 1 also shows the *throughput gap,* defined as the difference between desired net throughput and net process throughput. Large gaps indicate a strong need for corrective action. From the perspective of most managers, including those at our research sites, desired net throughput is an exogenous demand: a plant manager must produce enough to fill orders; a project manager strives to meet deadlines for the launch of new products.[4] Workers and managers have several options they can use to regulate production. Each forms a balancing, or negative, feedback loop that works to eliminate the throughput gap by raising net process throughput toward the desired rate. We divide these options into two classes: first- and second-order improvements and show them in figure 2.

Figure 2. Balancing feedbacks controlling throughput.



Note: The loop identifiers (e.g., B1) indicate whether a loop is a balancing (or negative) feedback or a self-reinforcing (or positive) feedback (see Sterman, 2000).

First-order improvement. First-order improvement activities seek to extract greater usable output from the existing process. Net process throughput can be increased through greater *worker effort*, which directly boosts gross throughput and, given the defect rate (process yield), net throughput. Increasing the utilization of existing resources by getting people to work harder forms a balancing feedback loop, labeled B1 in figure 2. Effort can be increased through greater focus on task, shorter breaks, and speeding the line. Before MCT, line supervisors primarily relied on the work-harder loop to achieve production objectives. Managers can also allocate

[4] Over the longer term, organizational performance also feeds back to desired net throughput. Persistent throughput gaps erode competitiveness; conversely, excess capacity can lead senior management to downsize or take actions to raise demand (e.g., cut prices, start new development programs). To keep the exposition simple, however, we omit these slower dynamics and treat desired throughput as an exogenous variable.

resources to correct defects, forming the balancing rework loop (B2). In product development, the rework loop was used extensively to complete projects on time. Managers might also respond to a throughput gap by expanding production capacity (e.g., hiring more workers or purchasing additional plant and equipment); but capacity expansion takes time, is costly, and is generally not an option for managers responsible for day-to-day operations (for models of the interactions between process improvement and capacity, see Sterman, Repenning, and Kofman, 1997, and Repenning, 2000). Capacity expansion was beyond the authority of participants in the improvement programs we studied.

Second-order improvement. First-order improvement can close the throughput gap, but only at significant and recurring cost. A more effective solution is to eliminate the process problems that generate defects (Deming, 1986). Instead of raising gross throughput by working harder, managers can allocate *resources to improve the process,* eventually increasing the rate at which process problems are discovered and corrected. As the stock of process problems falls, the rate of defect introduction drops, boosting net throughput and reducing the throughput gap, creating the balancing work-smarter loop (B3) shown in figure 2. Such second-order improvements require managers to train the workforce in improvement techniques, give them the freedom to deviate from established routines and experiment with potential solutions, and release them from their normal responsibilities (Deming, 1986; Wruck and Jensen, 1994).

Although there are some delays in the first-order work-harder and rework loops, these are generally quite short. Throughput gaps are usually recognized quickly—in the manufacturing plants we investigated, throughput was monitored shift by shift—and both workers and managers took corrective action (working harder and stepping up rework effort) within the same shift or at most in a few days. Working smarter, however, while yielding more enduring gains than working harder, often produces results only after a substantial delay. Building up the needed resources, learning to use improvement methods, carrying out experiments, and altering existing processes all take time. These delays are shown in figure 2 in the links between the throughput gap and problem correction. The length of the delays depends on the particular process. Schneiderman (1988) found that the improvement half-life—the time required to cut the defects generated by a process in half—depends on the technical and organizational complexity of the process. Relatively simple processes, such as improving the yield of a machine tool, have short half-lives, often less than a year. More complex processes, such as product development, have half-lives of several years or more.

Investments in first and second order improvement thus produce different dynamics. Working harder and doing rework produce immediate but temporary gains, while working smarter yields delayed but more enduring improvement. Building on this characterization, we now use our model to explain why the production systems we observed evolved to the undesirable state described above, first pursuing the question at an individual level of analysis and then extending our analysis to include both managers and workers.

THE DYNAMICS OF PROCESS IMPROVEMENT

Individual-level Cognitive and Perceptual Biases

While the value of eliminating process problems has long been recognized (Crosby, 1979; Deming, 1986; Juran, 1995), there are at least four reasons, rooted in basic cognitive processes, why working harder and correcting defects often take precedence over preventing defects: (1) process outputs are more salient than process problems; (2) investments in improvement only yield gains with a delay; (3) working harder and correcting defects produce more certain outcomes than engaging in improvement; and (4) managers often fail to realize that previous investments in producing defective material are sunk costs.

Salience. Process outputs (the actual products that are produced) are more salient and tangible than process problems, and people have repeatedly been shown to overweight available and salient features of the environment (Taylor and Fiske, 1975; Kahneman, Slovic, and Tversky, 1982). In manufacturing, defective products are physical objects, easily seen and touched. They accumulate in a pile sitting on the production floor. They are literally in the way. In contrast, process problems are often invisible, hidden in equipment or in relationships among components of the process. Similarly, in product development, projects close to launch are tangible and salient, while those in the early phases are concepts with few physical manifestations. A chief engineer described his organization's reluctance to allocate resources to the early phases of development, as the PDP process dictated:

> . . . if you are an engineer with a project close to job one, say 3 months, and . . . you are not ready to ship your product, that's a very visible and apparent problem. . . . Now, [suppose] you are thirty months ahead of job one, 2.5 years away, and you are lacking customer definition. You are trying to get the same level of attention [but] there is much more of a tendency to say, "Come on, quit crying and get on with it."

Delays. The delays between starting an improvement program and reaping its benefits are long and variable, while working harder quickly boosts throughput. Shifting resources from working harder and rework to improvement therefore often causes an immediate drop in throughput. Faced with this worse-before-better trade-off, people under pressure to close a throughput gap are likely to choose working harder and defect correction over prevention, even if they understand that doing so suppresses the symptoms without curing the disease. The executive in charge of PDP discussed the problem created by the long time delays in product development: "Imagine . . . the general manager . . . going up in front of the president and saying, 'We missed our profitability numbers because we spent extra money developing our new design process that won't be fully deployed . . . [for] five years. . . . Wasn't that a good move?'"

Uncertainty. First-order work yields more certain outcomes than second-order activities. It is usually clear when a defect has been corrected or how many widgets will be produced by an extra hour spent working harder. In contrast, the complexity and unobservability of process problems make it difficult to assess whether and when a proposed process change will result in fewer defects. Risk aversion is a basic feature of decision making, and people have also been shown to be ambiguity averse (Einhorn and Hogarth, 1985). Faced with a throughput gap, many managers prefer the more certain gain of production and defect correction to the ambiguous and uncertain yield of defect prevention. The executive in charge of PDP explained: ". . . taking the risk and spending incremental money that's not in your budget—even though in the long run it would have been the right thing . . . is a difficult thing to do. . . . The budget is something that's easy for your boss to tell you whether you hit it or not."

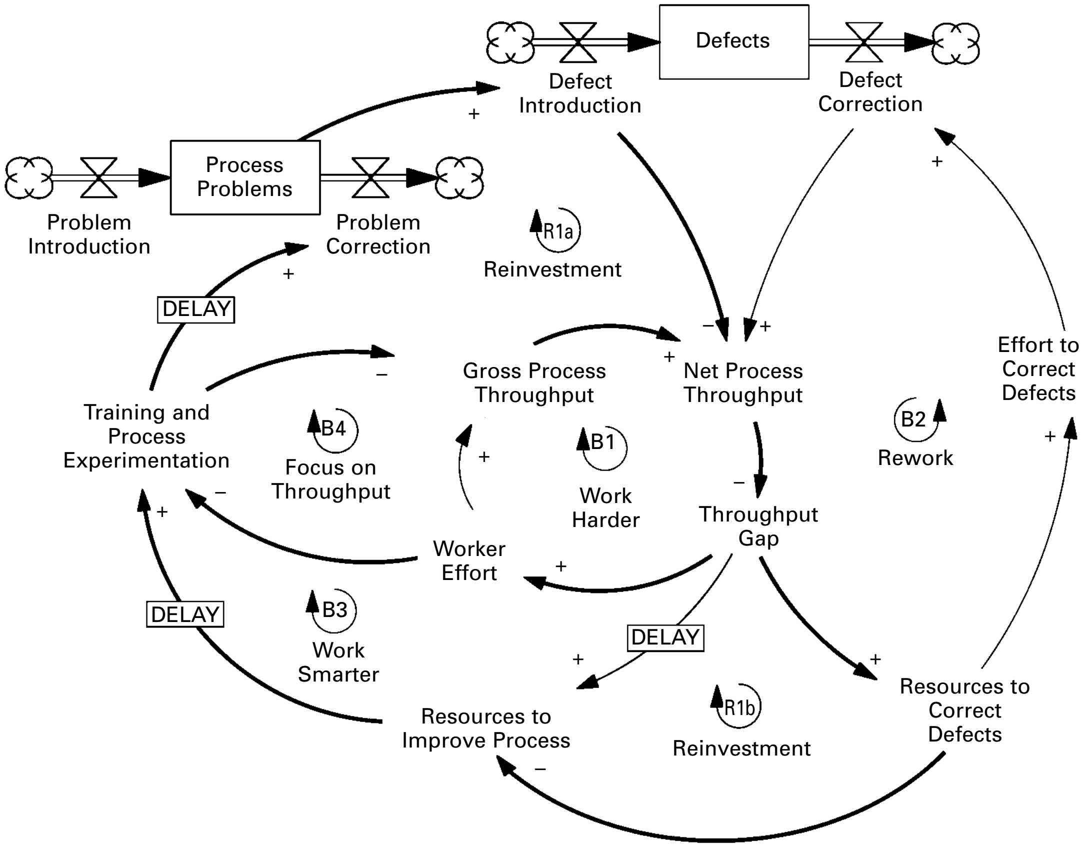
Sunk costs. Eliminating process problems, while preventing future defects, does nothing about the stock of defects already generated. The stock of defective output represents a substantial and tangible investment in materials, labor, and capital. Most accounting systems report the value of the inputs to each product, making it is easy to assess the benefit of investing in correction. In contrast, assessing the value of defect prevention is difficult. As one manager in our study said, ". . . nobody ever gets credit for fixing problems that never happened." The well-known sunk cost fallacy (Staw, 1976, 1981; Thaler, 1980; Arkes and Blumer, 1985) reinforces the bias toward correction. Managers often favor defect correction over prevention, as they see it, to recoup past investments in defective outputs, even though those investments are sunk costs.

Links between First- and Second-order Improvements

The challenge of investing in improvement and learning is increased by the interactions among first- and second-order improvement activities, which are shown in figure 3. Interconnections arise for two reasons. First, resources are finite. Line workers have limited time to allocate among production, defect correction, and process improvement; engineers must trade off doing their "real" design work against investing in process capability. Resource constraints, coupled with the biases against improvement, lead to two negative links, shown in figure 3: as worker effort rises, training and process experimentation suffer. Likewise, resources to improve process fall when people increase resources to correct defects.

A second interconnection arises because improvement usually requires a temporary reduction in throughput. In manufacturing, time devoted to improvement cannot be used for production. Further, machines must usually be taken off line to conduct experiments and correct process problems. Similarly, engineers attending training, practicing with new development tools, or experimenting with new technologies are not completing designs. We capture these short-run costs with the negative link from training and process experimentation to gross process throughput. The strength of this link depends on the available slack. If experiments can be run when machines are normally idle, and engineers can carry

Figure 3. Reinforcing feedbacks driving improvement.



out improvement activity when their services are not required on development projects, then the link is weak and the marginal cost of improvement is low. If machines and people are fully utilized, however, improvement activity cuts throughput sharply.

The new links close three important feedback loops. The first is the balancing focus-on-throughput loop (B4). Cutting improvement activity enables workers to increase gross output and close the throughput gap, but the resulting gains are temporary. Less improvement activity cuts the rate of problem correction, eventually leading to more process problems, more defects, and lower net throughput. Workers then face even more pressure to focus on throughput and respond by cutting improvement activity further, forming the self-reinforcing reinvestment loops, R1a and R1b. Unlike the loops described so far, the reinvestment loops are reinforcing feedbacks that tend to reinforce and amplify changes in throughput.

If there is a large throughput gap, for example, training and experimentation fall as workers focus on throughput. The drop in improvement activity causes process problems to accumulate, boosting defect generation and causing a still greater throughput gap (reinvestment loop R1a). Similarly, a larger throughput gap shifts resources toward defect correction and away from improvement. Process problems accumulate at a faster rate, leading to still more defects and a still greater throughput gap (reinvestment loop R1b). These loops operate in a variety of settings. For example, deferring preventive maintenance can lead to more machine breakdowns and still greater pressure to reassign maintenance mechanics from preventive to reactive work (Carroll, Sterman, and Marcus, 1997). Similarly, allocating resources to correct design defects late in a development cycle reduces the resources available to projects in earlier phases, leading to future problems and still fewer resources for new projects (Repenning, 2001). In such situations, the reinvestment loops operate as vicious cycles that accelerate the deterioration of the process, cutting throughput even as people work ever harder. Conversely, the reinvestment loops can operate as virtuous cycles. Successful improvement reduces defect generation and increases net process throughput, allowing workers to meet throughput goals with less time and effort and freeing additional resources for learning and improvement.

Whether an organization continues to learn and improve or stagnates is thus determined by the state of the reinvestment feedbacks. If these loops work in the upward, virtuous direction, performance will continue to improve. If, however, they work in the downward direction, the organization will be trapped in a vicious cycle of declining capability. Although, the upward direction is clearly preferable, many organizations, including the one we studied, often experience the opposite dynamic. To explain why, we introduce the capability trap.

The Capability Trap

The capability trap arises from the interactions between judgmental biases and the physical structure of work processes. For example, machine operators or design engineers facing a shortfall may initially work harder (loop B1), do more rework (loop B2), or focus on throughput (loop B4), all of which reduce the time available for improvement. These responses are tempting because they yield immediate gains, while their costs are distant in time and space, uncertain, and hard to detect. But, while throughput improves in the short run, the reduction in time dedicated to learning causes process capability to decline. Eventually, workers find themselves again falling short of their throughput target, forcing a further shift toward working and away from improving. Instead of making up for the improvement activity they skipped earlier, their own past actions, by causing the reinvestment loops (R1a and R1b) to work as vicious cycles, trap them in a downward spiral of eroding process capability, increasing work hours, and less and less time for improvement.[5]

The capability trap played an important role in the failure of improvement efforts in manufacturing prior to MCT. A line supervisor recalled:

> . . . supervisors never had time to make improvements or do preventive maintenance on their lines . . . they had to spend all their time just trying to keep the line going, but this meant it was always in a state of flux, which in turn, caused them to want to hold lots of

[5] The capability trap captures a different phenomenon than the competency trap highlighted by Levinthal and March (1993:106). As they noted, "As [organizations] develop greater competence at a particular activity, they engage in that activity more, thus further increasing competence and the opportunity cost of exploration." The competency trap arises from developing particular capabilities. The capability trap, in contrast, is a set of dynamics that prevent such capabilities from developing in the first place.

> protective inventory, because everything was so unpredictable. It was a kind of snowball effect that just kept getting worse.

In this case, supervisors relied on the work-harder and focus-on-throughput loops to hit their objectives, spending "all their time just trying to keep the line going." The reinvestment loops operate as vicious cycles, trapping the line at a minimal level of capability and preventing supervisors from engaging in improvement activities.

Similarly, in product development, the capability trap prevented the organization from reaping the gains of PDP. An engineering manager described the problems they had trying to implement the bookshelf of reusable designs: "An engineer might not take the time to document her steps or put the results of a simulation on the bookshelf and because of that she saved engineering time and did her project more efficiently. But in the long run it prevented us from being able to deploy the reusability concepts that we were looking for."

Just as machine operators faced a trade-off between producing and improving, development engineers were forced to choose between completing their assigned tasks and documenting what they learned for the benefit of future projects. And, just as the self-reinforcing reinvestment loops trapped the manufacturing operation in a state of low process capability, they prevented the organization from realizing potential productivity gains in product development.

Misperceptions of Feedback

While the literature and field data support the links in the model, our account of the capability trap raises several questions. First, wouldn't people recognize the existence of the reinforcing feedbacks that create the trap and take actions to avoid it? Second, if they find themselves stuck in the trap, wouldn't people learn to escape it by making appropriate short-term sacrifices? Studies of decision making in dynamic environments suggest that such learning is far from automatic.

Consider the outcome feedback received from a decision to spend more time working and less on improvement. Performance quickly increases, producing a clear, salient, unambiguous outcome. In contrast, the negative consequences of this action—the decline in process capability—take time, are hard to observe, and may have ambiguous interpretations. In experiments ranging from running a simulated production and distribution system (Sterman, 1989) to fighting a simulated forest fire (Brehmer, 1992) or managing a simulated fishery (Moxnes, 1999), subjects have been shown to grossly overweight the short-run positive benefits of their decisions while ignoring the long-run, negative consequences. Participants in these experiments produce wildly oscillating production rates, allow their fire-fighting headquarters to burn down, and find their fleets idled after overexploiting their fisheries. Applying these results to the system we studied suggests that learning will be slow at best and is likely to lead to dynamically impoverished mental models that emphasize short-run gains at the expense of long-run improvements.

Learning to avoid the capability trap is further complicated by the stock and flow structure relating improvement, process problems, and defect introduction. As long as the rate of problem correction exceeds the rate of problem generation, the stock of process problems declines and the reinvestment loops operate as virtuous cycles: fewer problems lead to fewer defects, increasing net process throughput and freeing more time for improvement. Reducing improvement activity may cause the rate of problem correction to drop, but as long as problems are corrected faster than they are introduced, the stock continues to fall. The reinforcing reinvestment loops are weakened but continue to operate as virtuous cycles, generating improvement, albeit at a slower pace, and a sense that improvement can be cut back with little risk. Continued cuts in improvement, however, eventually cause the rate of problem correction to fall below the rate of problem introduction. At this point, the stock of process problems stops falling and begins to swell, switching the reinforcing loops from virtuous to vicious cycles. Defects grow and net throughput falls, leading to still more pressure to cut improvement. Worse, the resulting decline in process capability occurs only with a long delay and is difficult to observe. While process capability erodes, many other variables are also changing, making it hard to associate any subsequent rise in defects with cuts in improvement effort made weeks, months, or even years before. By the time persuasive signals arrive to reveal the problem, the system is mired in the capability trap.

Once caught in the capability trap, people are also unlikely to learn to escape it. A new improvement program, by reducing the time available for throughput, causes an immediate and salient drop in performance, while its benefits are uncertain, delayed, difficult to assess, and may be insufficient to switch the reinforcing feedbacks to virtuous cycles. People are likely to conclude that the improvement program they attempted does not work and should be abandoned.

The analysis so far thus suggests that the dynamic complexity of process improvement can bias individuals against fundamental improvement, triggering a vicious cycle of declining learning and intensifying work pressure. Process improvement is not, however, an individual activity. Those assessing the throughput gap and giving directives are typically managers, while those actually allocating their time between working and improving are engineers and machine operators. The resulting group and organizational dynamics intensify the bias toward working harder.

Attribution Errors in Judging the Cause of Low Throughput

When choosing to emphasize first- or second-order improvement, managers must make a judgment about the causes of low process throughput. If they believe the cause of low performance lies in the physical structure of the process, they are likely to focus their efforts on process improvement. If, however, low throughput is thought to result from lack of worker effort or discipline, then managers are better off focusing on increasing the quantity of work. The cues people use to make causal attributions include temporal order, covariation, and contiguity in time and space (Einhorn and Hogarth, 1986). Attributing low throughput to inadequate worker effort is consistent with all these cues: worker effort immediately precedes the production of an item, production is highly correlated with worker effort, and workers and the items they produce are contiguous in time and space. In contrast, process problems typically precede low throughput with longer, variable, and often unobservable delays, are imperfectly correlated with low throughput, and can be located far from the defects they create. Managers are thus likely to attribute a throughput shortfall to inadequate worker effort, even when the true causes are systemic process problems.

Managers' tendency to attribute performance shortfalls to problems with the workforce rather than the production system is reinforced by the so-called fundamental attribution error, or dispositional bias. Attributing a problem or behavior to individuals rather than the systems in which they are embedded is a pervasive and robust phenomenon (Ross, 1977; Jones, 1979; Ross and Nisbett, 1991; Gilbert and Malone, 1995). While the degree to which the fundamental attribution error is either fundamental or an error continues to be debated (Harvey, 1981; see also Sabini, Seipman, and Stein, 2001), studies identifying the conditions that moderate dispositional bias suggest that managers in the situations we studied are particularly prone to overly dispositional attributions. For example, recent studies suggest that dispositional attributions are moderated when the salience of situational factors is enhanced (Quattrone, 1982; Krull and Dill, 1996), when additional cognitive effort is dedicated to generating alternative explanations for observed behavior (Krull and Dill, 1996; Lee, Hallahan, and Herzog, 1996; Krull et al., 1999), when people envision that they might be in the same role or position of those they are judging (Lee and Hallahan, 2001), and when people expect to justify their attributions to an authority (Tetlock, 1985). None of these conditions is likely to hold in the situations we studied. Process problems are often invisible and distant in time and space from the defects they create, while the connection between worker behavior and output is salient, immediate, and obvious. Similarly, at our study site, as in most organizations, managers and workers faced heavy workloads, reducing the time and attention available to consider alternative explanations that might moderate dispositional attributions. Moreover, few managers expect to ever be in workers' positions. And, while managers are accountable to their superiors, they are accountable for results—their ability to hit targets for throughput, cost, productivity, etc.—not their attributions about subordinates. Existing research thus suggests that managers facing throughput gaps are likely to conclude that workers, not the process, are the cause of low throughput, reinforcing the bias against fundamental improvement.

The Self-confirming Attribution Error

Blaming employees often leads to actions that emphasize working harder. Managers making such dispositional attributions may toughen the penalties for failure, as in manufacturing before MCT, when ". . . supervisors who missed their objectives knew they were going to get beat up . . .," and in product development, where ". . . they shoot you for missing product launch." More subtly, managers may also increase the frequency and granularity with which worker performance is monitored. For example, prior to MCT, utilization was often reported on a per-machine, per-shift basis. Similarly, a project manager we interviewed recalled that when a subsystem for which he was responsible fell behind schedule, his boss required him to call every hour with a status report until the prototype met the specifications. But, with experience, shouldn't managers correct their erroneous attributions, eventually realizing that low performance results from inadequate process capability rather than lazy employees? To the contrary, the cues people receive tend to reinforce rather than offset the dispositional bias, leading to the phenomenon of self-confirming attribution errors.

If managers attribute low performance to inadequate employee effort rather than process problems, the intendedly rational response is to pressure them to work harder. If, however, the workers are fully utilized, they will likely respond by focusing on throughput and cutting improvement effort. Managers observe that throughput rises but cannot easily determine how much of the gain is due to increased effort and how much results from cuts in learning, improvement, or maintenance. Because managers do not fully observe the reduction in improvement activity (they fail to account for the focus-on-throughput loop), they overestimate the impact of their get-tough policy. The rise in output provides powerful evidence reinforcing their initial, but incorrect, attribution that the workers just needed a kick in the pants. Managers quickly learn that boosting production pressure works—throughput rises when they turn up the pressure. Recall the project manager required to provide hourly status reports: the problem was soon solved, confirming the boss's belief that he had intervened appropriately, indeed had decisively taken charge of the situation, though the team was already working around the clock, and his interference drained precious time from their efforts to solve the problem.

Workers may unwittingly conspire in strengthening managers' attributions. Workers are naturally reluctant to tell supervisors they can't meet all their objectives. The more effectively workers cover up the process shortcuts they take, the less aware managers will be of the true costs of production pressure. Unaware that improvement activity, maintenance, and problem solving have been cut back, throughput appears to rise without requiring any sacrifices, reinforcing management's attribution that the workers really were lazy. Moreover, while throughput will eventually decline with decreased attention to working smarter, due to the delayed and diffuse nature of the cues indicating an erosion in process capability, managers are unlikely to attribute a throughput gap to pressure they placed on workers weeks or months before. They are likely to conclude instead that the workers have once more slacked off and require another dose of production pressure.

Managers' initial attributions that throughput problems result from the workers rather than the process are strongly self-confirming, driving the organization into the capability trap, where high production pressure squeezes out the improvement activity that could boost throughput and ease the pressure. Far more importantly, the vicious cycle of self-confirming attribution errors also changes managers' mental models by providing them with increasingly compelling evidence that the source of low throughput lies in the poor attitudes and weak character of the workforce. Evidence of these self-confirming attributions appears in two different guises in our data. As discussed earlier, senior managers in the PDP effort repeatedly attributed the difficulties they experienced to the undisciplined character of the engineering staff. When pressed to explain, many managers resorted to even deeper attributions. For example, when asked why engineers resisted project management, the manager in charge of PDP replied:

> Program management and the disciplines associated with it continue to be a problem in my opinion in most Western cultures. The people that are particularly rigorous and disciplined, the Japanese and the Germans, tend to be so by cultural norms. I can't tell you if it's hereditary or society or where it is they get it, but . . . there's a strong push back from the Western type of engineer for much of this.

There is no mention of structural features of the system or the pressure, felt throughout the organization, to deliver ambitious projects on time. Instead, this manager blames the failure on the undisciplined character of "Western" engineers. Such attributions, here generalized to entire nations and invoking a disturbing racial and ethnic subtext, are typical of the fundamental attribution error. Shared and repeated, such stereotypes become institutionalized in the corporate culture and can strengthen prejudices in society at large.

Whereas, in PDP, dispositional attributions appeared in explanations for failure, many managers attributed the success of the MCT effort to overcoming their tendency to blame workers. One supervisor, asked to account for the success of MCT, articulated this point clearly: "There are two theories. One says 'there's a problem, let's fix it.' The other says 'we have a problem, someone is screwing up, let's go beat them up.' To make improvement we could no longer embrace the second theory, we had to use the first." The general manager responsible for both MCT and PDP also reported a similar focus as a key component of both MCT and his success as a manager. He explained the source of his views:

> [At a previous job] I became a plant manager. . . . I'll never forget as long as I live. [The previous manager] started blaming his people for all his problems. . . . He was really on one guy very badly. . . . His view was the whole reason for the poor performance of the plant was because of this guy. So I didn't say anything or do anything and I took my time and I gave it about two or three months. Then I gave the guy more responsibility . . . as much responsibility as he'd take. He ended up being one of the best people in the plant. I guess that was probably the turning point.

Thus, while many managers in the PDP effort attributed the initiative's failure to the engineers, managers in manufacturing often attributed MCT's success to changing their own attributions, from people to the production system.

Institutionalizing the Attribution Error

While initially significant, the benefits of additional production pressure eventually decline. As workers become fully focused on throughput, they can no longer boost production by cutting the time spent on improvement. Faced with the declining efficacy of production pressure and given their attribution that employees are just not working hard enough, managers are likely to make physical changes to the production technology in an effort to monitor and control the activities of the workers (e.g., detailed work reporting systems, video surveillance, and software that measures data-entry keystroke rate). Unfortunately, such investments and workers' reactions to them not only worsen the attribution-error dynamics but also progressively embed those errors in the physical and institutional structure of the organization.

Substantial investments in monitoring and control systems not only reinforce managers' belief that these technologies are required (Strickland, 1958) but also potentially lead them to create evidence justifying their investments in surveillance (Lingle, Brock, and Cialdini, 1977). Conversely, tightly specified objectives and sophisticated monitoring technologies have been shown to create the behaviors that they are designed to prevent (e.g., Wilson and Lassiter, 1982). And even if workers and managers do not fall prey to these psychological dynamics, the combination of intense production pressure and close monitoring creates a set of incompatible objectives. Workers eventually have no choice but to evade or subvert management's controls, play games with performance metrics, or make ad hoc changes to the process. Once discovered, these workarounds provide powerful evidence confirming managers' initial attributions, justifying still greater investments in monitoring and control. But as managers strengthen incentives and controls, they make departures from them ever more necessary. What begins as a false attribution by management that workers are slothful, undisciplined, and untrustworthy becomes reality, creating an increasingly hostile and adversarial relationship between superiors and subordinates in the process. Both managers' and workers' worst fears are realized as a consequence of their own actions.

These dynamics were particularly clear in the pre-MCT period in manufacturing. Previous initiatives targeted at reducing WIP inventory created a direct conflict with the objectives of high machine and labor utilization. Operators and supervisors reacted by making ad hoc changes to the manufacturing process that allowed them to appear to satisfy both objectives. Many accumulated secret work-in-process inventories so they could keep their machines running, even when the output wasn't needed. A manager explained, "Supervisors at that time were evaluated on labor performance on a daily basis. It didn't take long for them to develop a buffer in front of their line so that if the schedule called for 700 and their line was fully utilized at 800, they could still run 800 units every day, and still make their labor performance." While the extra inventory helped supervisors hit their local objectives, it also increased cycle times, delayed quality feedback, and increased costs. The consequent low performance caused managers to scrutinize workers and supervisors more closely.

Similarly, while PDP required teams to pass a series of checkpoints requiring detailed progress reports, engineers often reported design phases as complete when, in fact, they were not. One engineer recalled that weekly project review meetings were labeled the "liar's club" because the engineers responsible for each subsystem always claimed to be on schedule, even when they were far behind. In response, managers would often tell the engineers they had less time than there actually was. A manager responsible for facilitating the use of PDP reported, ". . . [one] executive engineer used to have what I would call 'fighting meetings'. . . . His attitude was we should tell everybody that they're all red [behind schedule], they're all failing, they have to make changes faster [and] if we don't . . . we're going to shut the whole division down." Both behaviors compromised the integrity of the development process—delaying the revelation of problems led to more errors and expensive rework in other subsystems; telling teams they were behind schedule often led to shortcuts that created additional errors—generating additional production pressure and stress on both engineers and managers.

DISCUSSION

The results of our analysis come with the usual limitations associated with inductive studies. Studying two initiatives in a single organization limits the ability to generalize, and retrospective accounts are subject to hindsight bias. Yet, despite these limitations, by using a range of literatures to inform our analysis, our study helps integrate a number of diverse findings and perspectives into an emerging theory explaining both improvement and stagnation in organizations. Echoing Adler and Borys (1996), our theory begins with a distinction between two types of exploitation: finding and taking advantage of latent improvement opportunities in a production system (exploitation in the sense of March, 1991) versus appropriating the time and energy of those working within that system (exploitation in the sense of Marx). Distinguishing between these two senses of exploitation is important because they interact. As the MCT experience showed and others have argued (e.g., Deming, 1986; Wruck and Jensen, 1994), refining a complex technology requires the active participation of those who use it day to day. To succeed, participants require both the freedom to deviate from standard routines and the time to do so. When managers focus on appropriating peoples' time, however, they often limit the range of acceptable activity and place people under severe production pressure, inadvertently, but quite effectively, limiting learning and improvement. Others have recognized the fundamental incompatibility between the two types of exploitation (e.g., Adler and Borys, 1996; Pfeffer, 1998). Deming (1986: 71), for example, wrote, "A quota is a fortress against improvement. . . ."

Yet, while both practitioners and academics admonish managers to focus on the process, not the people, the widespread failure of improvement programs suggests that few are able to create and sustain the necessary organizational structures. Despite compelling evidence concerning the merits of TQM, high-performance human resource practices, and other innovations that rely on the contributions of front-line employees, managers seeking improvement find it difficult to resist the temptation to increase pressure and tighten controls. While compelling, the arguments of Deming and others have not been sufficient to change the focus of many managers.

The explanation for this phenomenon begins with the insights provided by theories of structuration and technology implementation. Implementation is a dynamic process that induces substantial and varied changes in the organizations that attempt it (e.g., Orlikowski, 1992, 1996), often resulting in different patterns of interaction and beliefs, depending on the context in which it takes place (Barley, 1986). In the case of process improvement and organizational learning, we found that the coevolution of actions, beliefs, and structures can both trap a system in a perpetual state of low capability and systematically mislead managers as to the true cause of low performance. The vicious cycle of self-confirming attributions not only leads to actions that prevent employees from engaging in improvement activities, it also reinforces managers' beliefs that few improvement opportunities exist. Prior to MCT, many, if not most managers came to believe that they worked with a fully exploited technology, thus justifying their focus on people rather than process. Yet, although the organization had fully appropriated its members' time and energy, managers were literally tripping over opportunities for improvement.

While researchers and managers often assume that a tightly controlled process is the consequence of having fully exploited the opportunities for learning (e.g., Sitkin, Sutcliffe, and Schroeder, 1994), our analysis suggests that the causality also runs in the opposite direction: the belief that a technology is fully exploited can result from tight control over the activities of the workforce. A focus on exploiting people can be strongly self-confirming, structuring an environment in which such actions appear to be the only path to success. Deming and others continually stressed the importance of focusing on the system rather than the people, and many people sincerely believe in the wisdom of working smarter. But without an understanding of the larger system, the temptation to pressure people to meet short-run objectives is strong. Succumbing to that temptation can drag the organization into the capability trap and teach managers and workers that the improvement methods they are trying to implement don't work, or don't work in their organization.

At this level, our analysis echoes the insights of March and colleagues (Levitt and March, 1988; March and Simon, 1993) about superstitious learning in organizations. In complex organizations, managers attend to a subset of the cues their actions generate, often leading to omissions in their assessments of important causal relationships; in particular, people frequently fail to recognize feedback processes (Sterman, 1994). Yet this insight too raises a significant question: why do some organizations get caught in such cycles while others do not? As documented by a number of authors and further supported by the MCT experience, organizations do, on occasion, achieve significant improvements in capability, suggesting that they are not all caught in the vicious cycle of self-confirming attributions all the time. The notion of reinforcing feedback has greatly contributed to understanding a variety of organizational pathologies (e.g., Merton, 1948; Hall, 1976; Perlow, 1999), yet, we know little about the variables that determine when such pathologies are likely to be present.

The answer to the above question highlights the most important contributions of our study. Our analysis extends existing approaches to understanding self-reinforcing relationships in organizations by specifying the physical and behavioral structures underlying the reinforcing loops that create pathological outcomes. The stock and flow structure that relates process problems to defects and process throughput results in two basic options for improvement, each with different dynamic characteristics: working harder and doing rework produce immediate but transient gains, while working smarter generates delayed but more enduring improvement. These options interact with scarce resources to create the reinforcing reinvestment loops that generate the capability trap. The vicious cycle of self-confirming attribution errors arises because decisions made in this system produce a complex set of cues on different time scales; the positive benefits of working harder, while transient, occur immediately while the permanent costs are incurred only with a delay. The principal benefits of this more operational characterization of the source of organizational pathology are sharp predictions concerning the environments most prone to the dysfunctional dynamics we identify: the longer the delay between investing in improvement and reaping the gains, the greater the variation in other variables during this interval, and the higher the utilization of resources, the more likely the system will suffer from self-confirming attribution errors and fall into the capability trap.

Comparing MCT and PDP illustrates the critical role that these characteristics play in determining the likely success of efforts to learn and improve. Prior to these programs, both manufacturing and product development were trapped in vicious cycles of stagnating capability and self-confirming attributions. Yet, though the same senior executive led both, MCT succeeded and PDP failed. The explanation lies in differing delays in manufacturing and product development. While cycle times in manufacturing were never more than a month, product development projects took over three years. Hence, in manufacturing, the general manager only had to maintain commitment to MCT for a few months before early results demonstrated its value. Quick payoffs also meant that little else changed in the meantime. There was little doubt that MCT was responsible for the improvement. Early productivity gains weakened the trade-off between working and improving. As capacity grew, the plants could shift an increasing fraction of their resources to improvement while still hitting production targets.

In contrast, the longer delays in product development made it far more difficult to break the vicious cycle of self-confirming attributions. Shifting engineers from working harder to working smarter immediately reduced throughput. Even under ideal conditions, the benefits would not have been observed for years. Meanwhile, changes in technology, personnel, organizational structure, and competition made it hard to attribute any gains that were realized to actions taken years before. In addition to reducing the perceived value of the new process—a behavioral effect—the lack of early results meant throughput pressure remained high—a physical effect. The continuing throughput pressure helped defeat PDP by making it difficult to undertake experiments, by reducing the time available for investments with high but delayed payoffs (such as the bookshelf), and by forcing the engineers to cut corners. While the feedback structure describing both initiatives was the same, differences in critical time delays contributed to radically different outcomes.

The inability of most organizations to reap the full benefit of innovations targeted at improving internal performance thus has little to do with the specific tool or technique they select. Blaming the tools is simply another type of attribution error that has diverted both managerial and scholarly attention from the source of the problems that organizations experience in implementing new innovations. Our study suggests that such difficulties lie neither solely in the production technology nor in the surrounding social context but, rather, are rooted in the ongoing interactions among the physical, economic, social, and psychological structures in which implementation takes place. Further progress will thus require crossing the disciplinary boundaries that currently define organizational inquiry. Whereas theories originating in operations management and industrial engineering largely ignore the beliefs and behaviors of those working with the production technology, organizational theories generally do not account for the physical structure of the organization and its processes (Dean and Bowen, 1994). Only by integrating these current disparate perspectives, however, are organizational scholars likely to resolve the paradox posed by useful innovations that so often go unused.

REFERENCES

Adler, P., and B. Borys
1996 "Two types of bureaucracy: Enabling and coercive." Administrative Science Quarterly, 41: 61–89.

Argote, L.
1999 Organizational Learning: Creating, Retaining, and Transferring Knowledge. Boston: Kluwer Academic.

Arkes, H. R., and C. Blumer
1985 "The psychology of sunk cost." Organizational Behavior and Human Decision Processes, 35: 124–140.

Barley, S. R.
1986 "Technology as an occasion for structuring: Evidence from observations of CT scanners and the social order of radiology departments." Administrative Science Quarterly, 31: 78–108.

Brehmer, B.
1992 "Dynamic decision making: Human control of complex systems." Acta Psychologica, 81: 211–241.

Carroll, J., J. Sterman, and A. Markus
1997 "Playing the maintenance game: How mental models drive organization decisions." In R. Stern and J. Halpern (eds.), Debating Rationality: Nonrational Elements of Organizational Decision Making: 99–121. Ithaca, NY: Cornell University/ILR Press.

Covey, S.
1989 The Seven Habits of Highly Effective People. New York: Simon and Schuster.

Crosby, P.
1979 Quality is Free. New York: McGraw-Hill.

Cyert, R., and J. G. March
1992 A Behavioral Theory of the Firm. (Originally published in 1963.) Cambridge, MA: Blackwell.

Dean, J. W., and D. Bowen
1994 "Management theory and total quality: Improving research and practice through theory development." Academy of Management Review, 19: 392–418.

Deming, W. E.
1986 Out of the Crisis. Cambridge, MA: MIT Center for Advanced Engineering Study.

Easton, G., and S. Jarrell
1998 "The effects of total quality management on corporate performance: An empirical investigation." Journal of Business, 71: 253–307.

Einhorn, H. J., and R. M. Hogarth
1985 "Ambiguity and uncertainty in probabilistic inference." Psychological Review, 92: 433–461.
1986 "Judging probable cause." Psychological Bulletin, 99: 3–19.

Eisenhardt, K. M.
1989 "Building theories from case study research." Academy of Management Review, 14: 532–550.

Fine, C.
1986 "Quality improvement and learning in productive systems." Management Science, 32: 437–444.

Giddens, A.
1984 The Constitution of Society: Outline of the Theory of Structure. Berkeley, CA: University of California Press.

Gilbert, D., and P. Malone
1995 "The correspondence bias." Psychological Bulletin, 117: 21–38.

Glaser, B. G., and A. L. Strauss
1967 The Discovery of Grounded Theory: Strategies for Qualitative Research. Chicago: Aldine.

Goldratt, E. M., and J. Cox
1986 The Goal: A Process of Ongoing Improvement, rev. ed. Croton on Hudson, NY: North River Press.

Hackman, J. R., and R. Wageman
1995 "Total quality management: Empirical, conceptual, and practical issues." Administrative Science Quarterly, 40: 309–342.

Hall, R. I.
1976 "A system pathology of an organization: The rise and fall of the old *Saturday Evening Post*." Administrative Science Quarterly, 21: 185–211.

Hannan, M. T., and J. Freeman
1984 "Structural inertia and organizational change." American Sociological Review, 49: 149–164.

Harvey, J.
1981 "Do we need another gloss on attribution theory?" British Journal of Social Psychology, 20: 301–304.

Hendricks, K. B., and V. R. Singhal
1996 "Quality awards and the market value of the firm: An empirical investigation." Management Science, 42: 415–436.

Ishikawa, K.
1985 What is Total Quality Control? Englewood Cliffs, NJ: Prentice-Hall.

Johnsson, F.
1996 "Sustainable improvement programs: Total quality excellence." Unpublished Master's thesis, MIT Sloan School of Management.

Jones, E.
1979 "The rocky road from acts to dispositions." American Psychologist, 34: 107–117.

Juran, J.
1995 A History of Managing for Quality. Milwaukee, WI: ASQC Quality Press.

Kahneman, D., P. Slovic, and A. Tversky
1982 Judgment under Uncertainty: Heuristics and Biases. Cambridge: Cambridge University Press.

Keating, E., and R. Oliva
2000 "A dynamic theory of sustaining process improvement teams in product development." In M. Beyerlein and D. Johnson (eds.), Advances in Interdisciplinary Studies of Teams, 5: 245–281. Greenwich, CT: JAI Press.

Klein, K., and J. Sorra
1996 "The challenge of innovation implementation." Academy of Management Review, 21: 1055–1080.

Krull, D., and J. Dill
1996 "On thinking first and responding fast: Flexibility in social inference processes." Personality and Social Psychology Bulletin, 22: 949–959.

Krull, D., M. Loy, J. Lin, C. Wang, S. Chen, and X. Zhao
1999 "The fundamental fundamental attribution error: Correspondence bias in individualist and collective cultures." Personality and Social Psychology Bulletin, 25: 1208–1219.

Lee, F., and M. Hallahan
2001 "Do situational expectations produce situational inferences? The role of future expectations in directing inferential goals." Journal of Personality and Social Psychology, 80: 545–556.

Lee, F., M. Hallahan, and T. Herzog
1996 "Explaining real-life events: How culture and domain shape attributions." Personality and Social Psychology Bulletin, 22: 732–741.

Levinthal, D., and J. G. March
1993 "The myopia of learning." Strategic Management Journal, 14: 95–112.

Levitt, B., and J. G. March
1988 "Organizational learning." Annual Review of Sociology, 14: 319–340.

Lingle, J., T. Brock, and R. Cialdini
1977 "Surveillance instigates entrapment when violations are observed, when personal involvement is high, and when sanctions are severe." Journal of Personality and Social Psychology, 35: 419–429.

March, J. G.
1991 "Exploration and exploitation in organizational learning." Organization Science, 2: 71–87.

March, J. G., and H. A. Simon
1993 Organizations, 2d ed. Oxford: Blackwell.

Merton, R.
1948 "The self-fulfilling prophecy." Antioch Review, 8: 193–210. Reprinted in R. Merton (1968), Social Theory and Social Structure. New York: Free Press.

Miles, M., and A. M. Huberman
1984 Qualitative Data Analysis. Newbury Park, CA: Sage.

Moxnes, E.
1999 "Misperceptions of bioeconomics." Management Science, 44: 1234–1248.

Oliva, R., and J. Sterman
2001 "Cutting corners and working overtime: Quality erosion in the service industry." Management Science, 47: 894–914.

Orlikowski, W. J.
1992 "The duality of technology: Rethinking the concept of technology in organizations." Organization Science, 3: 398–427.
1996 "Improvising organizational transformation over time: A situated change perspective." Information Systems Research, 7: 63–92.

Perlow, L.
1999 "The time famine." Administrative Science Quarterly, 44: 57–81.

Perlow, L., G. Okhuysen, and N. Repenning
2002 "The speed trap: Exploring the relationship between decision making and temporal context." Academy of Management Journal, vol. 45 (in press).

Pfeffer. J.
1997 New Directions in Organizational Theory. New York: Oxford University Press.
1998 The Human Equation. Boston: Harvard Business School Press.

Pfeffer, J., and R. I. Sutton
2000 The Knowing-Doing Gap. Boston: Harvard Business School Press.

Powell, T.
1995 "Total quality management as competitive advantage: A review and empirical study." Strategic Management Journal, 16: 15–37.

Quattrone, G.
1982 "Overattribution and unit formation: When behavior engulfs the person." Journal of Personality and Social Psychology, 42: 593–607.

Repenning, N.
2000 "Drive out fear (unless you can drive it in): The role of agency in process improvement efforts." Management Science, 46: 1385–1396.
2001 "Understanding fire fighting in new product development." Journal of Product Innovation Management, 18: 285–300.
2002 "A simulation-based approach to understanding the dynamics of innovation implementation." Organization Science, 13: 109–127.

Rigby, D.
2001 "Management tools and techniques: A survey." California Management Review, 43 (2): 139–159.

Ross, L.
1977 "The intuitive psychologist and his shortcomings: Distortions in the attribution process." In L. Berkowitz (ed.), Advances in Experimental Social Psychology, 10: 174–214. New York: Academic Press.

Ross, L., and H. Nisbett
1991 The Person and the Situation: Perspectives of Social Psychology. Philadelphia: Temple University Press.

Sabini, J., M. Seipman, and J. Stein
2001 "The really fundamental attribution error in social psychological research." Psychological Inquiry, 12: 1–15.

Sastry, M. A.
1997 "Problems and paradoxes in a model of punctuated organizational change." Administrative Science Quarterly, 42: 237–275.

Schneiderman, A.
1988 "Setting quality goals." Quality Progress, April: 55–57.

Senge, P.
1990 The Fifth Discipline. New York: Doubleday.

Sitkin, S., K. Sutcliffe, and R. Schroeder
1994 "Distinguishing control from learning in total quality management: A contingency perspective." Academy of Management Review, 19: 537–564.

Staw, B. M.
1976 "Knee-deep in the Big Muddy: A study of escalating commitment to a chosen course of action." Organizational Behavior and Human Performance, 16: 27–44.
1981 "The escalation of commitment to a course of action." Academy of Management Review, 6: 577–587.

Sterman, J. D.
1989 "Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment." Management Science, 35: 321–339.
1994 "Learning in and about complex systems." System Dynamics Review, 10: 291–332.
2000 Business Dynamics: Systems Thinking and Modeling for a Complex World. Chicago: McGraw-Hill/Irwin.

Sterman, J., N. Repenning, and F. Kofman
1997 "Unanticipated side effects of successful quality programs: Exploring a paradox of organizational improvement." Management Science, 43: 503–521.

Strickland, L.
1958 "Surveillance and trust." Journal of Personality, 26: 200–215.

Taylor, S. E., and S. T. Fiske
1975 "Point of view and perceptions of causality." Journal of Personality and Social Psychology, 32: 439–445.

Tetlock, P.
1985 "Accountability: A social check on the fundamental attribution error." Social Psychology Quarterly, 48: 227–236.

Thaler, R.
1980 "Towards a positive theory of consumer choice." Journal of Economic Behavior and Organization, 1: 39–60.

Tushman, M. L., and E. Romanelli
1985 "Organizational evolution: A metamorphosis model of convergence and reorientation." In L. L. Cummings and B. M. Staw (eds.), Research in Organizational Behavior, 7: 171–222. Greenwich, CT: JAI Press.

Weick, K. E.
1979 The Social Psychology of Organizing, 2d ed. New York: Random House.
2000 "Quality improvement: A sensemaking perspective." In R. E. Cole and W. R. Scott (eds.), The Quality Movement and Organization Theory: 155–172. Thousand Oaks, CA: Sage.

Westphal, J. D., R. Gulati, and S. M. Shortell
1997 "Customization or conformity? An institutional and network perspective on the content and consequences of TQM adoption." Administrative Science Quarterly, 42: 366–395.

Wheelwright, S., and K. Clark
1995 Leading Product Development. New York: Free Press.

Wilson, T. D., and G. D. Lassiter
1982 "Increasing intrinsic interest with superfluous constraints." Journal of Personality and Social Psychology, 42: 811–819.

Wruck, K. H., and M. C. Jensen
1994 "Science, specific knowledge, and total quality management." Journal of Accounting and Economics, 18: 247–287.

Zbaracki, M. J.
1998 "The rhetoric and reality of total quality management." Administrative Science Quarterly, 43: 602–636.