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Flexibility Versus Efficiency? A Case Study of Model Changeovers in the Toyota Production System

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This is a careful and insightful case study of how the Toyota Production System manages the paradox of efficiency and flexibility, which arises periodically in connection with model changeovers. The authors detail the functioning of four organizational mechanisms—metaroutines, partitioning, switching, and ambidexterity. However, of particular interest is the contextual reinforcing role of training and trust in administrative structures, procedures, and rules.

Arie Y. Lewin

Abstract

This article seeks to reconceptualize the relationship between flexibility and efficiency. Much organization theory argues that efficiency requires bureaucracy, that bureaucracy impedes flexibility, and that organizations therefore confront a tradeoff between efficiency and flexibility. Some researchers have challenged this line of reasoning, arguing that organizations can shift the efficiency/flexibility tradeoff to attain both superior efficiency and superior flexibility. Others have pointed out numerous obstacles to successfully shifting the tradeoff. Seeking to advance our understanding of these obstacles and how they might be overcome, we analyze an auto assembly plant that appears to be far above average industry performance in both efficiency and flexibility. NUMMI, a Toyota subsidiary located in Fremont, California, relied on a highly bureaucratic organization to achieve its high efficiency. Analyzing two recent major model changes, we find that NUMMI used four mechanisms to support its exceptional flexibility/efficiency combination. First, metaroutines (routines for changing other routines) facilitated the efficient performance of nonroutine tasks. Second, both workers and suppliers contributed to nonroutine tasks while they worked in routine production. Third, routine and nonroutine tasks were separated temporally, and workers switched sequentially between them. Finally, novel forms of organizational partitioning enabled differentiated subunits to work in parallel on routine and nonroutine tasks. NUMMI's success with these four mechanisms depended on several features of the broader organizational context, most notably training, trust, and leadership.

(*Flexibility*; *Bureaucracy*; *Tradeoffs*; *Routines*; *Metaroutines*; *Ambidexterity*; *Switching*; *Partitioning*; *Trust*)

Introduction

The postulate of a tradeoff between efficiency and flexibility is one of the more enduring ideas in organizational theory. Thompson (1967, p. 15) described it as a central "paradox of administration." Managers must choose between organization designs suited to routine, repetitive tasks and those suited to nonroutine, innovative tasks. However, as competitive rivalry intensifies, a growing number of firms are trying to improve simultaneously in efficiency- and flexibility-related dimensions (de Meyer et al. 1989, Volberda 1996, *Organization Science* 1996). How can firms shift the terms of the efficiency-flexibility tradeoff?

To explore how firms can create simultaneously superior efficiency and superior flexibility, we examine an exceptional auto assembly plant, NUMMI, a joint venture of Toyota and GM whose day-to-day operations were un-

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der Toyota control. Like other Japanese auto transplants in the U.S., NUMMI far outpaced its Big Three counterparts simultaneously in efficiency and quality and in model change flexibility (Womack et al. 1990, *Business Week* 1994).

In the next section we set the theoretical stage by reviewing prior research on the efficiency/flexibility tradeoff. Prior research suggests four mechanisms by which organizations can shift the tradeoff as well as some potentially serious impediments to each mechanism. We then describe our research methods and the NUMMI organization. The following sections first outline in summary form the results of this investigation, then provide the supporting evidence in our analysis of two major model changeovers at NUMMI and how they differed from traditional U.S. Big Three practice. A discussion section identifies some conditions underlying NUMMI's success in shifting the tradeoff and in overcoming the potential impediments to the four trade-off shifting mechanisms.

Flexibility Versus Efficiency?

There are many kinds of flexibility and indeed a sizable literature devoted to competing typologies of the various kinds of flexibility (see overview by Sethi and Sethi 1990). However, from an organizational point of view, all forms of flexibility present a common challenge: efficiency requires a bureaucratic form of organization with high levels of standardization, formalization, specialization, hierarchy, and staffs; but these features of bureaucracy impede the fluid process of mutual adjustment required for flexibility; and organizations therefore confront a tradeoff between efficiency and flexibility (Knott 1996, Kurke 1988).

Contingency theory argues that organizations will be more effective if they are designed to fit the nature of their primary task. Specifically, organizations should adopt a mechanistic form if their task is simple and stable and their goal is efficiency, and they should adopt an organic form if their task is complex and changing and their goal is therefore flexibility (Burns and Stalker 1961). Organizational theory presents a string of contrasts reflecting this mechanistic/organic polarity: machine bureaucracies vs. adhocracies (Mintzberg 1979); adaptive learning based on formal rules and hierarchical controls versus generative learning relying on shared values, teams, and lateral communication (McGill et al. 1992); generalists who pursue opportunistic *r*-strategies and rely on excess capacity to do well in open environments versus specialists that are more likely to survive in competitive environments by pursuing *k*-strategies that trade less flexibility for greater efficiency (Hannan and Freeman 1977, 1989). March (1991) and Levinthal and March (1993) make the parallel argument that organizations must choose between structures that facilitate exploration—the search for new knowledge—and those that facilitate exploitation—the use of existing knowledge.

Social-psychological theories provide a rationale for this polarization. Merton (1958) shows how goal displacement in bureaucratic organizations generates rigidity. Argyris and Schon (1978) show how defensiveness makes single-loop learning—focused on pursuing given goals more effectively (read: efficiency)—an impediment to double-loop learning—focused on defining new task goals (read: flexibility). Thus, argues Weick (1969), adaptation precludes adaptability.

This tradeoff view has been echoed in other disciplines. Standard economic theory postulates a tradeoff between flexibility and average costs (e.g., Stigler 1939, Hart 1942). Further extending this line of thought, Klein (1984) contrasts static and dynamic efficiency. Operations management researchers have long argued that productivity and flexibility or innovation trade off against each other in manufacturing plant performance (Abernathy 1978; see reviews by Gerwin 1993, Suárez et al. 1996, Corrêa 1994). Hayes and Wheelwright's (1984) product/process matrix postulates a close correspondence between product variety and process efficiency (see Safizadeh et al. 1996).

Strategy researchers such as Ghemawat and Costa (1993) argue that firms must chose between a strategy of dynamic effectiveness through flexibility and static efficiency through more rigid discipline. In support of a key corollary of the tradeoff postulate articulated in the organization theory literature, they argue that in general the optimal choice is at one end or the other of the spectrum, since a firm pursuing both goals simultaneously would have to mix organizational elements appropriate to each strategy and thus lose the benefit of the complementarities that typically obtain between the various elements of each type of organization. They would thus be "stuck in the middle" (Porter 1980).

Beyond the Tradeoff?

Empirical evidence for the tradeoff postulate is, however, remarkably weak. Take, for example, product mix flexibility. On the one hand, Hayes and Wheelwright (1984) and Skinner (1985) provide anecdotal evidence that more focused factories—ones producing a narrower range of products—are more efficient. In their survey of plants across a range of manufacturing industries, Safizadeh et al. (1996) confirmed that in general more product variety was associated with reliance on job-shop rather continuous processes.

On the other hand, Kekre and Srinivasan's (1990) study of companies selling industrial products found that a broader product line was significantly associated with lower manufacturing costs. MacDuffie et al. (1996) found that greater product variety had no discernible affect on auto assembly plant productivity. Suárez et al. (1996) found that product mix flexibility had no discernible relationship to costs or quality in printed circuit board assembly. Brush and Karnani (1996) found only three out of 19 manufacturing industries showed statistically significant productivity returns to narrower product lines, while two industries showed significant returns to broader product lines. Research by Fleischman (1996) on employment flexibility revealed a similar pattern: within 2-digit SIC code industries that face relatively homogeneous levels of expected volatility of employment, the employment adjustment costs of the least flexible 4-digit industries were anywhere between 4 and 10 times greater than the adjustment costs found in the most flexible 4-digit industries.

Some authors argue that the era of tradeoffs is behind us (Ferdows and de Meyer 1990). Hypercompetitive environments force firms to compete on several dimensions at once (*Organization Science* 1996), and flexible technologies enable firms to shift the tradeoff curve just as quickly as they could move to a different point on the existing tradeoff curve. Echoing this thesis at a more theoretical level, Nelson and Winter (1982) argue that the concept of a production possibilities frontier is itself misleading because in the real world, production technologies are largely tacit and managerial rationality is essentially bounded, and therefore moving up to or beyond a hypothetical frontier represents a challenge that is qualitatively no different from moving to a different point along such a frontier.

In response to these empirical findings and theoretical arguments, other researchers argue that while the tradeoff can be shifted, much of what we observe when firms make notable improvement in several dimensions at once represents catching up to best practice (Skinner 1996, Hayes and Pisano 1996, Clark 1996). Pushing the best practice frontier, they argue, is a far more difficult task, since tradeoffs are inevitable when organizations must make difficult-to-reverse commitments in plants, equipment, and capabilities in their implementation of a given strategy.

We conclude from these statistical results and theoretical debates that if there is a tradeoff between efficiency and flexibility among the average performers in an industry, at any point in time some firms are below and others above this tradeoff line. It is not difficult to see how firms might find themselves below this line; but what do firms need to do to position themselves above it? More intriguingly, how can exceptional firms shift beyond the tradeoff experienced by even their strongest rivals?

This question is not new in organizational theory: the challenge of simultaneously performing both routine and nonroutine tasks has been explored in a number of studies of the "ambidextrous" organization (Duncan 1976, McDonough and Leifer 1983, Jelinek and Schoonhoven 1993, Tushman and O'Reilly 1997; see also overview in Daft 1998). Reviewing these studies and culling indications from the broader literature suggests four kinds of organizational mechanisms that can help shift the tradeoff. *Metaroutines* systematize the creative process. *Job enrichment* enables workers to become more innovative and flexible even in the course of their routine tasks. *Switching* differentiates roles for dealing with the two kinds of tasks, thus allowing workers time to focus on each. And *partitioning* differentiates structures for dealing with each kind of role, and the resulting specialization permits subunits to refine their capabilities in each activity, and permits routine and nonroutine activities to be carried out simultaneously in parallel. We first describe these mechanisms, then identify in the organizational research literature several potentially important limitations of each.

First, the cost of output flexibility can be reduced if the associated internal processes can be made more routine. Schumpeter (1976) argued that large corporations had a competitive advantage over smaller firms because they were able to routinize the innovation process at least to some extent. The operations management literature has argued that flexible computer-based automation (computer-numerically controlled machine tools, computer aided manufacturing, flexible manufacturing systems, etc.) reduces the cost of high product variety (Adler 1988). Strategies such as mass customization (Pine 1993) that are based on economies of scope (Goldhar and Jelinek 1983) and economies of substitution (Garud and Kumaraswamy 1995) rely on metaroutinization as effected through greater product modularity (specifying standardized interfaces), parts standardization, or software-based process automation. The underlying insight here is that organizations can develop metaroutines both for changing among established routines and for inventing new routines (Nelson and Winter 1982, Volberda 1996, Grant 1996).

Metaroutines shift the tradeoff by transforming nonroutine into more-routine tasks; but organizations can also become more ambidextrous by developing their innovativeness in nonroutine tasks without impairing their efficiency in routine tasks. In the literature to date, we have identified three mechanisms that facilitate this kind of ambidexterity. They can be arrayed from more microscopic to more macroscopic in scale: enrichment, switching, and partitioning.

First, workers' routine production tasks can be enriched to include improvement as well as efficiency goals. Langer (1989) and Schon (1983) discuss the difference between mindless and mindful performance of routine work (see also Louis and Sutton 1991). Victor et al. (forthcoming) show that in a TQM environment, production workers doing their regular production work tasks can be attentive simultaneously to the efficient implementation of routine production procedures and to the nonroutine task of identifying improvement opportunities. These workers may not sit down to document a suggestion until the shift is over, but much of the requisite discovery and analysis can be done on the job.

Second, work can be organized so that people switch sequentially between the two types of tasks rather than attempting to do them both simultaneously. As compared to enrichment, switching allows greater focus and reduces the risk of confusion. Such switching can be supported by "parallel" organizational structures such as quality circles. These structures enable people to move back and forth between a bureaucratic structure for the routine tasks and a more organic structure for the nonroutine tasks (on parallel structures, see Bushe and Shani 1991, Stein and Moss Kanter 1980, Miller 1978; for closely related concepts, see also Zand 1974 on collateral organizations, Goldstein 1985 on dualistic organizations, and Nonaka and Takeuchi 1995 on hypertext organizations).

Finally, ambidexterity can be supported on an even more macroscopic scale if the organization as a whole partitions itself to allow some subunits to specialize in routine tasks while other subunits specialize in nonroutine tasks. Partitioning has some advantages over enriching and switching, because enriching and switching do not afford as much opportunity to deepen skills by specialization, and do not allow sustained, focused efforts directed at the two types of tasks to proceed simultaneously. As the relative importance of nonroutine tasks increases, it becomes more cost-effective for the firm to partition its basic structure into separate units that can be staffed by specialized personnel and structured and managed differently to assure their optimal performance (Lawrence and Lorsch 1967). Miles and Snow's (1978) Analyzer type of firm uses this mechanism to compete on both efficiency and innovation fronts against the organizationally simpler Defender and Prospector types. If partitioning is to enhance flexibility without great loss of efficiency, the differentiated subunits must effectively coordinate and integrate their efforts. Organization theory suggests when one or both of the subunits' tasks are nonroutine, this coordination and integration cannot rely on the core bureaucratic mechanisms of hierarchy and standardization, but it can in principle be achieved using the mechanism of mutual adjustment in lateral relations between the subunits (Thompson 1967, Mintzberg 1979).[1]

Potential Impediments

Prior research has recognized that these four mechanisms—metaroutines, enriching, switching, and partitioning—face a number of potentially serious intrinsic impediments. Taking metaroutines first, we need to distinguish the cases where metaroutines are embodied in computer software from those where they are embodied in employees' work. Research has reached a rather strong consensus on the changes in organizational form that allow software-based automation to shift the tradeoff: because such automation reduces the routineness of the tasks left to workers, the appropriate organizational structure shifts towards the organic (Zammuto and O'Connor 1992). But research is far less definitive on cases where firms seek to shift the tradeoff frontier by organizational means rather than by advanced automation. Our theoretical analysis and our fieldwork reported below therefore focus on such cases, and here the literature suggests a number of factors that make shifting the tradeoff problematic.

Insofar as it affects tasks directly rather than being embodied in automation, metaroutinization is associated with two complementary impediments. On the one hand, powerful psychological forces encourage "goal displacement" so that conformance to the standardized procedures becomes the over-riding goal, and the remaining nonroutine tasks are ignored (Merton 1958). This defensiveness will be amplified if, as is often the case, the results of the routine tasks are more easily measured and are the focus of reward systems. When employees cling to existing routines—and metaroutines, while meta, are still routines—they will see the introduction of new routines as a threat. As a result, metaroutines can lead to organizational rigidity.

On the other hand, metaroutines, like routines more generally, reduce task autonomy and variety compared to pure, unfettered innovation. Thus, metaroutines may reduce the intrinsic motivational quality of the innovation process (Hackman and Oldham 1980). For example, skilled trades maintenance workers might resent the standardization of their creative, problem-solving process when formalized "total preventive maintenance" procedures are introduced. Design engineers might resent detailed procedures specifying tasks that must be performed at each stage of the design process. While some employees might welcome routinization as a relief from the stresses created by the chaotic quality of the nonroutine, others—perhaps those with higher growth needs strength—might resist it. Assuming that resistance is the more likely response, some theorists have argued that routinization typically needs to be imposed on employees by management via the efforts of staff specialists (Mintzberg 1979). The demotivating effects of such coercive routinization might not be too costly to the firm if the resulting tasks were entirely stable and routine, since in such contexts a passively acquiescent workforce might suffice (as in Bowen and Lawler's (1992) assembly-line model). However, a firm relying on its employees to contribute to ongoing innovation and learning would surely hesitate before adopting such an approach.

While a long line of researchers have argued for the effectiveness of job enrichment—primarily on the grounds that it strengthens motivating job characteristics—other researchers have argued that enrichment has a number of potentially important intrinsic limitations. First, it is costly, since it requires more training of production workers: when the core tasks are routine, the skills required for nonroutine tasks will go relatively unused for lengthy periods. Second, enrichment, at least as it is usually interpreted, is typically paired with job enlargement—enrichment adds new "vertical" tasks while enlargement adds new "horizontal" tasks to jobs in the routine production domain. Such job redesign often militates against precise conformance with standardized production procedures, since cycle times become longer and workers have more autonomy in deciding work methods and pacing. Conformance, however, may be necessary for efficiency and indeed for organizational learning in routine task environments (Adler and Cole 1993). Third, by introducing nonroutine tasks into the workers' job description, enrichment reduces the programmability and observability of tasks, creating information asymmetries and increasing opportunities for opportunistic behavior; this increases agency costs (Eisenhardt 1989). These three limitations imply that enrichment may simply shift the organization along the existing tradeoff curve—towards more flexibility at the cost of reduced efficiency—rather than shifting the tradeoff curve itself.

Switching too encounters potentially serious impediments. Systematic investigations of the effectiveness of switching structures such as quality circles have revealed mixed results (see Ledford et al. 1988). A disturbing proportion of such structures do not yield the expected performance or attitudinal gains, and their mortality rate is high (Lawler and Mohrman 1985). The underlying inhibiting factors reflect a basic tension between the two roles. The efficient performance of routine tasks requires the support of a mechanistic organizational form, one where workers are often assumed to experience work as a disutility and managers must therefore exercise close supervision of detailed prescriptive procedures (Bowen and Lawler 1992). The creative performance of nonroutine tasks requires the support of an organic form, where employees are assumed to be intrinsically motivated and managers are urged to function as facilitators and coaches. The compliance-oriented, Theory X style of management required in routine tasks conflicts with the high commitment, Theory Y style required in innovative tasks (Walton 1985, McGregor 1960). Duncan argues that employees who have been involved in the nonroutine tasks associated with innovation "are likely to initially resist more centralization in rules and procedures and decision making"—organizational changes necessary for high performance in the more routine, implementation stage (Duncan 1976, p. 180).

Finally, several strands of research suggest that the subunit partitioning approach may not be able to shift the tradeoff, since the coordination and integration of differentiated subunits requires extensive and expensive management effort. The coordination of tasks across separately managed subunits requires more planning and management attention. It is difficult and costly to reconcile the different "thought worlds" that arise in the differentiated subunits (Dougherty 1992). The maintenance of different organization structures each with its own policies and practices leads to additional organizational overhead (Bowen and Lawler 1995, p. 78). Partitioning may lead to parochial, self-interested subunit behavior, multiplying the overhead required to reconcile intraorganizational conflict (Pfeffer 1978, Duncan 1976). New management positions have to be added to coordinate and integrate the differentiated subunits and resolve their conflicts (Lawrence and Lorsch 1967). For all these reasons, Mitzberg (1979, pp. 340–342) argues that mutual adaptation between differentiated units often fails in machine-bureaucracies.

Contextual Factors

Our presentation of the prior research as summarized in the literature review above is framed in terms of mechanisms and their intrinsic limitations; other strands of research can be interpreted as suggesting that the organizational context will determine the relative balance of the forces mobilized by the mechanisms and those associated with their intrinsic limitations. Organizational theory has long argued that formal structures and processes are always embedded in—and their effectiveness conditioned by—a broader organizational context of culture and leadership (see e.g., Scott 1992).

Prior research on ambidextrous, tradeoff-shifting organizations has identified some of these contextual factors. Tushman and O'Reilly (1997) analyze several ambidextrous organizations that are able simultaneously to pursue evolutionary and revolutionary innovation. They see the key sources of ambidexterity in: (a) a decentralized structure (read: partitioning) in which headquarters functions as a facilitator rather than as a "checker and controller," (b) a common, underlying layer of strong culture and vision which is complemented by another layer of culture that is differentiated between evolutionary and revolutionary parts of the organization (read: partitioning) or between the corresponding phases of activity (read: switching), and (c) supportive leaders and flexible managers. They thus show that distinctive values, culture, and leadership are essential contextual conditions for ambidexterity. Jelinek and Schoonhoven's (1993) study of high-tech firms that excelled at both efficient production and product technology innovation highlights a similar set of contextual factors.

These two studies are rich in insights, but have not generated an overarching theory. In the absence of such a theory, and with the goal of moving closer towards one, this study therefore adopts an inductive, theory-building approach rather than a deductive, theory-testing approach.

Research Context and Methods

A case study of an organization that excels in both efficiency and flexibility dimensions can advance our understanding of these hypothesized mechanisms and impediments and of how the organizational context influences their relative effects. NUMMI was one such organization. In analyzing NUMMI's flexibility, we focus on its agility in major model changes.

Research Context: Model Changeovers in the Auto Industry

Beginning in the 1970s, the auto industry "dematured" (Abernathy et al. 1983). Whereas the bases of competition in the U.S. during the prior period were price and cosmetic styling, the new epoch brought ferocious competition from Japanese manufacturers who shifted consumer expectations concerning price and conformance-type quality while simultaneously differentiating products through design and technology. Products thus changed more rapidly and the changes were more substantial. Minor cosmetic model changes still occurred each year, but the frequency of major model changes—and the extent of product and process change associated with them—increased. Whereas the interval between major model changes in the U.S. Big Three auto companies had varied between four and eight years, competitive pressure led to a shift toward the lock-step four-year cycle adopted by Japanese companies and their U.S. subsidiaries.

These major model changes represented a huge challenge to an auto assembly plant. Anywhere between 60% and 90% of the 1500–2000 components that were assembled into a vehicle were redesigned, and as a result, most of both internal and supplier manufacturing processes were redesigned too. The ability of a manufacturing plant to introduce new models—the time and cost required to "ramp up" production of the new model to targeted quality and efficiency levels—thus represented a form of flexibility that had considerable and growing strategic significance (Gerwin 1993, p. 398).[2]

NUMMI operated at exceptional levels of productivity and quality. In 1993, for example, NUMMI took around 18 person-hours to assemble a vehicle, as compared to an average of 22 hours in a large sample of Big Three plants (Pil and MacDuffie 1996: note that their analysis controls for numerous factors that can distort interplant comparisons). And in the J. D. Power and Associates' Initial Quality Survey that year, NUMMI's three main products scored either first or second place in their respective market segments: the Corolla had 82 problems per 100 vehicles, the Prizm had 87, and the Tacoma truck had 77, compared to an auto industry average of 107.

At the same time, NUMMI was significantly more flexible than its Big Three counterparts. Whereas Ford, Chrysler, and GM model changes in 1994 involved plant closures of 60, 75, and 87 working days respectively, NUMMI was closed for only five days for comparably complex major model changeovers in 1993 and 1995. Whereas the typical Big Three plant often took six months to resume normal production rates after a major model change, NUMMI took less than four months for the 1993 changeover and less than three months for the 1995 changeover. Moreover, quality at Big Three plants typically degraded considerably at resumption of operations: during the 1987–1995 period, J. D. Power Initial Quality data shows that the average number of problems per 100 domestic model vehicles went from 135 in the year prior to model change to 144 problems in the year of the model change. And the typical Big Three plant only returned to its normal quality level after a period lasting anywhere from three months to over a year. By contrast, NUMMI's 1993 model introduction took only a few weeks to recover from a small slip from world-class levels: from 87 to 89 for the Prizm, from 82 to 85 for the Corolla. (Note that the J. D. Power and Associates data are collected on vehicles sold in the September through December period each year. Since most model changes occur in August, the annual J. D. Power and Associates scores are thus very sensitive to quality during the ramp-up of new models.)

As we show below, one of the key factors explaining NUMMI's agility was its use of a Pilot Team composed of production workers. This Pilot Team designed the new production process, suggested changes to product design to facilitate production, and trained line workers for their new assignments. By contrast, the traditional Big Three changeover process left the design of the new product and production process to engineers and managers. In recent years, the Big Three have tried to become more agile, and in each company there had been a small number of projects that imitated the Japanese Pilot Team approach. Some of these projects have rivaled NUMMI's changeover performance. However, the agility shown in these exceptional projects had not yet become the norm within any of the Big Three (*Business Week* 1994).

Research Methods

In order to understand how NUMMI achieved its exceptional efficiency and flexibility, we conducted approximately 60 interviews during 1993 and 1994. Our informants came from NUMMI, UAW Local 2244, and Cal-OSHA (California Occupational Safety and Health Agency). Using a snowball approach, we interviewed individuals from all ranks of the company, including production workers, skilled trades workers, Team Leaders, Group Leaders, Assistant Managers, Managers, and senior executives. Interviewees came from a variety of functions, including assembly, the model change Pilot Team, quality engineering, assembly engineering, labor relations, safety, and training. We interviewed union officials from both the contending factions within Local 2244 (the Administration Caucus and the People's Caucus). As we explain below, the 1993 model changeover occasioned citations by Cal-OSHA—citations that were appealed by NUMMI and subsequently settled—and as a result, we also interviewed officials at Cal-OSHA. Information on Toyota's model change process was also drawn from interviews with managers, engineers, and workers at TMMK, Toyota's subsidiary in Georgetown, Kentucky.

Interviews were semistructured, and each lasted 30 to 60 minutes. Key informants were interviewed at greater length and in some cases several times. Most interviews were conducted by at least two researchers, and they were taped and transcribed. Unless otherwise noted, quotations below come from these interviews. All informants were asked about their work history, their roles in changeovers, and their experience of changeovers. Informants were also asked about specific topics on which they had specialized knowledge, such as facets of organizational history or policies.

Many informants had previously worked for Big Three auto companies, and their responses formed the basis of our characterization of the traditional Big Three changeover practices. We found no systematic studies of Big Three changeover practices outside the short descriptions in Clark and Fujimoto (1991) and Clark et al. (1992). Concerned that our informants may have been biased, we submitted drafts of our characterization of these practices for review by several managers currently with Big Three companies: no bias surfaced.

To supplement these interviews, we examined a broad range of company and union documents, union newspapers, minutes from union-management meetings, and training materials for workers and managers. We also studied the materials used to support and contest the Cal-OSHA citations filed at the state Department of Industrial Relations in Oakland, California. We relied on previously published studies and our own earlier rounds of interviews for descriptions of NUMMI's earlier years.

Shifting the Tradeoff: Key Findings

In accordance with the canons of inductive research, we present our results first, in this section, then present the supporting evidence in the following three sections. Our results fall under two broad headings: mechanisms and context.

A higher-order result should, however, be noted first. The literature reviewed above focuses on the internal organization of the firm; but we found that NUMMI's ambidexterity was very dependent on the nature of its supplier relations. The same four generic mechanisms were used by NUMMI in its supplier relations, and their effectiveness was conditioned by the broader context formed by the fabric of NUMMI's supplier relations. We therefore weave our discussion of the role of supplier relations into the more general storyline below.

Tradeoff-Shifting Mechanisms

Our first set of results are summarized in Exhibit 1. The first and third columns of Exhibit 1 summarize the discussion above of tradeoff-shifting mechanisms and their possible impediments. The second column lists the various mechanisms that allowed NUMMI to shift the terms of the tradeoff relative to traditional Big Three practice.

First, NUMMI had many more metaroutines than traditional Big Three plants to guide the performance and increase the efficiency of nonroutine activities. Standardized problem-solving procedures facilitated continuous improvement efforts in regular production. Accumulated documentation of changeover experiences facilitated the

Exhibit 1 Key Findings

Trade-off Shifting Mechanism	NUMMI Changeover Mechanisms	Possible Impediments	Factors at NUMMI Mitigating Possible Impediments
METAROUTINES: Standardized procedures for changing existing routines and for creating new ones	• Problem-solving process is standardized in six-step procedure • Pilot Team relies on extensive documentation • Changeover process has documented template for suppliers • *Hansei* (reflection-review) process is standardized	• Routinization reduces task variety and autonomy compared to unconstrained creativity, and therefore reduces intrinsic motivation, which creates resistance or reduces commitment • If employees resist it, routinization must be imposed by management and staff, further reducing commitment	• Workers participate in standardization processes • Control over the outcomes of standardized processes is shared • Well-designed metaroutines provide structure and role clarity that are seen as useful in performing nonroutine tasks • Trust by subordinates that routines will be used as "tools" not "weapons"

ENRICHMENT: Add nonroutine tasks to routine production tasks	• *Kaizen* is worker's responsibility:
	  • During job design process (standardized work)
	  • During regular production
	  • During acceleration
	• *Kaizen* is suppliers' responsibility
	  • During contract period
	  • Between contracts
		• Training is costly and skill only rarely used, so efficiency is lost
		• Associated horizontal job enlargement reduces consistency
		• Enrichment gives more autonomy and therefore increases the risk of opportunism
			• Complementary investment in support for worker *kaizen* (specific training, job rotation, engineering support, management incentives), which leads to a considerable flow of useful ideas
			• The core work-cycle remains very short and highly standardized
			• Numerous management practices and human resource management practices create high mutual trust and thereby reduce the risk of opportunism

SWITCHING: Separate times for routine and nonroutine tasks and switch employees between them sequentially	• *Kaizen* is also conducted off-line, in QC circles
	• Production workers participate in *kaizen* activities during pilot runs
	• Workers rotate through Pilot Team
	• Suppliers polled for improvement ideas after each changeover project
		• Conflicting expectations in two roles: high autonomy and therefore high commitment in nonroutine roles *versus* low autonomy and therefore low commitment in routine roles	• NUMMI ensures that routine work is not alienating:
			  • Participative leadership and culture
			  • Worker training
			  • Supportive teams
			  • Employment security
			  • Gainsharing
			• High mutual trust between managers and workers in each other's competence and commitment
			• Union voice adds credibility to management commitments

PARTITIONING: Create subunits that specialize in routine or in nonroutine tasks	• A new partition is created: Pilot Team
	• An old partition is eliminated: production workers do methods engineering
	• Responsibilities are redistributed across existing partitions
	  • Suppliers do more design work
	• There is close and early mutual adjustment between:
	  • Design
	  • Engineering
	  • Manufacturing engineering
	  • Production management
	  • Suppliers
		• Additional overhead is required to support different structures in differentiated subunits
		• New subunits need to be integrated, but integration mechanism are costly
		• Subunits with differentiated goals tend to parochial behavior
		• Mutual adjustment between subunits is undermined by the bureaucratic context
			• Assignments to the Pilot Team are temporary rather than permanent, which helps keep goals and values aligned across subunits
			• The Pilot Team works in close daily interaction with production, and does much of its work on the shop floor, which reduces parochialism
			• The Pilot Team is matrixed into both Engineering and Manufacturing management to balance their respective concerns
			• Mutual adjustment is front-loaded, minimizing need for it later in the project (when it is more expensive)
			• Early mutual adjustment efforts strive to create standards that simplify downstream coordination
			• Metaroutines for changeover management facilitate mutual adjustment
			• Enrichment and switching mechanisms improve objective and perceived quality of changes proposed by Pilot Team
			• High levels of trust between interdependent units

work of the Pilot Team and guided interactions with suppliers. And a structured reflection-review procedure facilitated efforts to improve changeover management from project to project.

Second, NUMMI derived considerable tradeoff-shifting benefit from the enrichment of routine production tasks. Continuous improvement was defined as a key additional responsibility of production workers, indeed of all NUMMI personnel. Workers were encouraged to pull the "andon cord" to signal problems in their work and stop the line if necessary. NUMMI's managers put a premium on mindfulness in the conduct of routine activities. Workers' suggestions were particularly important during the acceleration of production on the new model: here workers were actively mobilized to identify problems and propose solutions to help the acceleration. Instead of leaving job design to a methods engineering department—NUMMI had no such department—workers were actively involved in the process of job design and redesign through the "standardized work" process.

Suppliers' tasks were also enriched. The traditional Big Three approach defined suppliers' role as simply fulfilling the terms of their purchase agreement and assuring that their products met the specifications provided by the company. By contrast, NUMMI mobilized suppliers' product design capabilities, and expected—and provided support for—continuous improvement and innovation in both the suppliers' products and their internal processes.

Third, a broad range of policies encouraged workers to switch easily between production and improvement tasks. Workers improvement ideas were developed not only on-the-job during regular production but also in off-line Quality Circle meetings. Workers participated in pilot production runs, where they helped identify problems and improvement opportunities. And workers were also given temporary assignments to the Pilot Team.

Fourth, NUMMI shifted the tradeoff by creating new partitions, reallocating tasks across partitions, eliminating dysfunctional partitions, and improving coordination and integration between partitions. The Pilot Team was a novel specialized unit, working alongside an engineering changeover team, responsible for designing the work process for the new model and for training workers for their new assignments. Responsibilities were reallocated across existing partitions, in particular through job enrichment for workers and more active involvement of suppliers. The traditional specialized methods engineering department was eliminated, and work methods were determined by workers on the line. Various partitioned units—within the plant, within other parts of the corporation, and suppliers—interacted intensively to assure effective mutual adjustment.

These mechanisms had distinct but mutually reinforcing tradeoff-shifting benefits. Metaroutines increased the efficiency of a given level of flexibility. Metaroutines also indirectly encouraged greater flexibility by facilitating the identification of anomalies whose resolution represented opportunities to further increase flexibility. The direct effect of the remaining three mechanisms was to increase the organization's innovation capabilities and thereby its flexibility. They also indirectly encouraged greater efficiency when these innovation capabilities were directed at improving ongoing operations.

Contextual Factors

The results summarized in the final column of Exhibit 1 suggest that the four tradeoff-shifting mechanisms functioned far more effectively at NUMMI than at the Big Three in part because these mechanisms were embedded in a very different organizational and inter-organizational context. Our analysis of the NUMMI case highlighted two key features of this context: training and trust.

Training was critical. If people lack the knowledge, skills, and abilities required for the effective implementation of the four basic mechanisms, the tradeoff cannot be shifted. NUMMI invested far more than Big Three plants in worker training. They also invested more than the Big Three in supplier "technical support."

Trust proved to be a second critical contextual factor. All four of the tradeoff-shifting mechanisms are vulnerable to failures of one or another of the three principle kinds of trust: consistency, competence, and congruence (generalizing from Sako's typology of kinds of inter-firm trust (1992): contract, competence, and goodwill).

First, lack of consistency trust—i.e., lack of trust that the other party will do what they said they would (Sako's (1992) contract trust, and Mishra's (1996) reliability trust)—can undermine support for metaroutinization and for the other three mechanisms. NUMMI's culture placed a high premium on consistency, on "walking the talk." Top management commitment to this value was enacted in the use of cross-level forums in which breakdowns of consistency could be surfaced and dealt with under norms of "fact-based management" rather hidden by parochial politics. The credibility of this commitment was buttressed by strong union voice.

Second, in many organizations managers and subordinates distrust each other's competence to fulfill their commitments (the Sako (1992) and Mishra (1996) competence trust, the Mayer et al. (1995) ability trust). NUMMI's extensive training investments assured high levels of worker competence. NUMMI's extensive technical support for suppliers motivated high levels of trust in supplier competence. NUMMI thus moved from inspecting incoming parts to certifying the ability of the suppliers to produce parts that met specification. And management competence was buttressed by high levels of investment in training for first-level managers and a policy of promotion from within.

Third, all four mechanisms can easily be undermined by lack of trust in goal congruence (Sako's (1992) goodwill trust, Mishra's (1996) openness and concern). Lack of congruence trust is commonly encountered in the conflict between horizontally differentiated subunits within the organization, between vertical layers in the organization, and between suppliers and customers. At NUMMI, "teamwork" was a core value expressed not only in the organization of workers into small production teams, but also in the ethos governing relations between departments and vertical layers, as well as in labor and supplier relations. Divisive political motives were dampened by top management's commitment to "fact-based management." The union's voice in the governance of the plant strengthened workers' confidence that management decisions would reflect common goals and not only corporate goals.

All three kinds of trust appeared in both interpersonal and system forms. Alongside the three types of interpersonal trust, NUMMI performance was also predicated on stakeholders' trust in the consistency, competence, and congruence of NUMMI's management system, its supplier relations systems, and its labor relations system.

Finally, alongside trust proper, we also found a range of mechanisms that induced trust-like behavior through what has been called "calculative trust." For example: NUMMI's work organization made its success dependent on front-line employees' efforts. By making its own success a hostage to employees' goodwill, NUMMI management committed itself to not taking advantage of opportunities to hurt the workforce. (Management's difficulties in living up to its implicit promises to act as if it internalized the workforce's goals are discussed below and analyzed further in Adler et al. 1997).

The following sections provide supporting evidence for these findings. We begin with describing in more detail the relevant company background.

Company Background

The GM plant in Fremont, California, closed its doors in 1982, idling 5,700 workers laid off over the course of its slow demise since the late 1970s. In a troubled company, this was one of the most troubled plants. Unexcused absenteeism often ran over 20 percent. Quality levels and productivity were far below the GM norm, which itself was falling ever further behind the world-class standard then being set in Japan. Labor relations were highly antagonistic.

In December 1984, a new company, New United Motors Manufacturing, Inc. (NUMMI), took over the old plant. NUMMI was a joint venture between GM and Toyota. GM provided the factory and would market half the plant's output, and Toyota invested $100 million and would assure the day-to-day management of the plant.

Like the factory, the workforce and union were largely inherited from the GM days. The personnel selection process was done jointly by the union and management, and laid-off GM-Fremont workers had hiring priority. Very few of these applicants were turned away. When production began in December 1984, 99 percent of the assembly workers and 75 percent of the skilled trades workers were former GM-Fremont employees and UAW members. NUMMI rehired the entire union hierarchy.

By 1986, NUMMI had achieved productivity levels almost twice those of GM-Fremont in its best years, 40 percent better than the typical GM assembly plant, and very close to the level of NUMMI's sister plant in Takaoka, Japan (Krafcik 1989). It was also producing the highest quality levels of any domestic auto plant. In 1988, the company switched from the Corolla FX and Nova to the regular Corolla and a new nameplate, the Geo Prizm. Through the mid-1990s, the plant continued to improve in quality and productivity, producing some 200,000 Corollas and Prizms a year.

In 1989, Toyota announced that it would invest another $350 million to expand the plant and begin production of Toyota compact pick-up trucks. With a capacity to build 125,000 trucks, the new line opened in September 1991. By 1993, NUMMI was producing about 120,000 trucks which, along with Toyota's imported trucks, were rated number one in initial quality by J. D. Power and Associates.

When NUMMI started up, the trauma of layoffs and the influx of an entirely new group of managers contributed to unfreezing old attitudes. However, NUMMI's continued improvements in quality and efficiency and the persistence for over a decade of dramatic differences between the performance of NUMMI and that of comparable Big Three plants must be attributed primarily due to NUMMI's management approach, particularly its use of the Toyota Production System and supporting management policies (Ohno 1988, Monden 1983). The following brief overview of these policies shows the extent to which workers' tasks were enriched and improvement activities were subject to metaroutinization.

NUMMI's Production System

The Toyota Production System (TPS) structured the work process at NUMMI under several complementary policies: team organization, just-in-time production, level production, mixed-model production, visual control, standardized work, and continuous improvement. Workers at NUMMI were divided into teams of four to six, each of which had a union member as Team Leader. Jobs were very modestly enlarged: work cycles remained at the industry norm of about 60 seconds, but Team Members often rotated jobs within their team. This not only relieved boredom and ergonomic strains, but gave workers a broader understanding of the production system. Jobs were also modestly enriched, by giving production workers some responsibility for quality, minor maintenance tasks, and line-side housekeeping. Team Leaders functioned primarily as lead hands, with modest administrative responsibilities but no managerial authority.

Under standardized work, each job was analyzed and the optimal method was specified in motion-by-motion instructions prescribing exactly how each job should be performed. However, NUMMI's approach to time-and-motion analysis differed from the traditional Big Three's version. At GM-Fremont, 80 industrial engineers designed the work process, monitoring and timing workers at specific jobs. At NUMMI, by contrast, there were no methods engineers: Team Members and Team Leaders themselves identified the optimal procedures for each job. Moreover, at NUMMI these procedures were subject to continuous improvement (*kaizen*). Workers were encouraged to *kaizen* their jobs and suggest improvements to the standardized work sheets. Workers were all trained in Toyota's six-step problem-solving procedure. Suggestions that passed muster became the new prescription, but only until the cycle was renewed by the next suggestion.

Under mixed-model production, if the month's delivery schedule called for a production mix of 75 percent of model A and 25 percent of model B for example, NUMMI would produce the same model mix each day, and three model A cars moving down the line would alternate with one model B. Big Three plants, by contrast, did not aggressively seek to reduce setup times, and they therefore batched similar products, producing one model for several hours at a time. Mixed model production both relied on and forced high levels of mindfulness in routine production.

In 1991 NUMMI also introduced quality circles (called Problem Solving Circles), where volunteers from a work group selected and studied a problem for several weeks over a lunch provided by the company. PSCs were not introduced earlier, since Toyota's philosophy was that workers and managers needed time to accumulate the prerequisite knowledge, skills, abilities, and mutual trust.

NUMMI's Management System

NUMMI's implementation of the Toyota Production System was buttressed by management policies that encouraged worker commitment and skill formation. One important set of commitment-enhancing policies involved relations with the union. NUMMI and the UAW used a joint problem-solving approach on many issues that were closely-guarded management prerogatives at GM-Fremont. In addition, the collective bargaining agreement promised a measure of job security. The company's successful efforts to avoid layoffs during a mid-1980s downturn greatly enhanced employees' confidence in the company's no-layoff commitment. *Kaizen* activity was encouraged by a gainsharing system rewarding all workers for improvements in plant-wide quality and efficiency: since its introduction in 1990, it paid out $645 in 1992, $733 in 1993, $1,285 in 1994, $1,130 in 1995, and $1,316 in 1996.

NUMMI also pursued many avenues for skill formation. New hires received more than 250 hours of training during their first six months on the job, while the average Big Three auto worker received 42 hours in their first year (MacDuffie and Kochan 1995). Team Member cross-training was required for job rotation, and this training was carefully tracked by Team Leaders. NUMMI's policy of promotion from within for skilled trades, Team Leaders, and Group Leaders was accompanied by an extensive set of training opportunities. Not only did promotions entail further training, but to be considered for advancement to any of these positions, workers were required to participate in company-sponsored training on their own time.

A Distinctive Kind of Bureaucracy

Consistent with the predictions of organization theory concerning organizations whose primary tasks are very routine, NUMMI was a very bureaucratic organization, in the technical sense of the term. Formalization and standardization were extensive. Standardized work and other kinds of detailed formal procedures governed daily operations. Even the very modest degree of flexibility required in NUMMI's routine operations relied on extensive formalization and standardization: mixed-model production standardized job sequences and relied on formalized Job Instruction training and detailed standardized work charts; quality circles used a standardized problem-solving process. Work teams were of the traditional rather than the self-directed type. While workers participated in defining work methods, changes in methods were often initiated by management and engineering, and where changes were initiated by workers their ideas had to be accepted by the team on the opposing shift and by the relevant supervisors. Vertical and horizontal differentiation were also extensive. NUMMI had a relatively tall hierarchy with six levels between the worker and the CEO, which was about the same number of levels as at GM-Fremont. While NUMMI had eliminated the methods engineering staff, it had unusually large staff groups in human resources, quality engineering, and production control.

This bureaucracy, however, did not function in the manner depicted in much conventional theory. Workers were actively involved in defining formalized procedures and in refining them over time. Departures from procedure were typically treated as opportunities for learning rather than as threats to authority. Under the influence of top managers' values and the union's power, lower-level managers were encouraged to maintain a participative rather than autocratic style. While lower levels did not have much autonomy to make decisions without prior consultation with superiors, this apparent centralization usually took the form of "fact-based" dialogue based on expertise rather than command-and-control domination based on positional authority (consistent with Lincoln and Kalleberg's (1991) finding that Japanese organizations had more *de jure* centralization but also more *de facto* participation than comparable American organizations). An extensive system of formal controls was buttressed and complemented by extensive informal controls, and both formal and informal controls were to a large measure joint rather than imposed, insofar as their design and functioning were strongly influenced by employees and by the union.

As a result, and contrary to the expectations of a long line of organization theorists, NUMMI's highly bureaucratic form was associated with high levels of work motivation and commitment (Adler 1993). Management conducted confidential employee surveys every two years; since these were conducted on work time, participation rates were over 90 percent. In these surveys, the proportion of Team Members reporting themselves satisfied with their job increased progressively from 65 percent in 1985 to some 90 percent in 1991, 1993, and 1995. Although the absence rate had climbed from about 2.5 percent to 3 percent over recent years, this rate was still less than half the industry average. Participation in the suggestion program grew progressively to over 90 percent. Involvement in problem-solving circles was increasing over time. Personnel turnover remained under 6%. And the plant still produced some of the highest quality small cars and light trucks in the United States, with quality and efficiency levels that continued to improve over time.

The '93 Model Change

How does an organization so finely tuned for the efficient performance of a repetitive task deal with the challenge of flexibility? In this section we examine how NUMMI introduced two new passenger cars that differed substantially from each other and from the models they replaced at the same time as it introduced important new process technology. We do this through a narrative account of NUMMI's introduction of the 1993 model-year Corolla and Prizm, and a comparison with traditional Big Three practice. In the following section, we describe how NUMMI learned from the weaknesses of this 1993 changeover to improve the changeover on the truck line to the 1995 model Tacoma truck.

NUMMI's Model Change Process

In the traditional American system, the vehicle design department first developed its sketches and clay models, then the engineering department converted these to engineering specifications. The engineering department in turn passed these specifications to the manufacturing staff at division headquarters, who specified the basic equipment and line configuration. The staff finally passed these process specifications to the plant engineers, who installed equipment on the factory floor and organized the assembly tasks. Workers were laid off for the time needed to retool, then recalled when the new equipment was ready.

The advantage of the Big Three's sequential approach was that downstream departments could wait to begin work until the immediately upstream department was done. To the extent that artifacts such as specifications and drawings provided sufficient guidance for the downstream departments' work, this approach reduced coordination costs. The success of this approach, however, depended on the upstream departments' ability to predict the constraints facing the downstream departments. Gaps in this knowledge would surface when the downstream department found, for example, that two mating parts did not fit even though they met specifications. The risk of the sequential, "throw the drawings over the wall" approach was thus that misfits would only be discovered late in the process, at which point a round of mutual adjustment would be initiated. The industry rule-of-thumb was that the cost to rectify a given error increases by a factor of about 10 with each of the four or five major phases of a new vehicle development project. A problem uncovered after release to manufacturing could—and often did—cost hundreds of thousands of dollars to rectify and weeks or months of delay in the new model launch.

At NUMMI and Toyota, designers, product engineers, plant engineers, production workers, and suppliers collaborated from the beginning of the changeover planning cycle. Instead of the traditional Big Three sequential model, NUMMI and Toyota saw the interdependence of these groups as reciprocal, and as one that therefore required extensive mutual adaptation (see Thompson 1967).

Manufacturing's involvement in the preparations for NUMMI's 1993 model change began very early, in 1989, as soon as the previous major model change was completed. Toyota design engineers began collecting problems and suggestions from NUMMI as well as from Toyota's other plants in Japan and Canada. By early 1990, over a year prior to their model changeover, NUMMI's sister plant in Takaoka had posted engineers to work with the design team and had begun reviewing the emerging product designs and identifying production process issues. NUMMI's model change would lag Takaoka's by a year; but later in 1990, over two years before NUMMI's changeover, the US factory became involved in the preparation process, and a team of engineers from NUMMI and representatives of NUMMI suppliers began visiting Japan to work with the vehicle designers, the corporate Production Engineering department, and their Takaoka counterparts.

The early interactions between design, engineering, and manufacturing personnel facilitated the timely discovery of many misfits. It also allowed for more creativity in improving fit quality, through aggressive efforts in value engineering. The goal of this collaboration—indeed, the "secret" to NUMMI's model changeover agility according to a senior Toyota manager—was rigorous certification prior to the resumption of operations that "man [read: workers], machines, materials, and methods" were capable of doing their intended jobs. Not only did this certification dramatically reduce the number of changes required after start of production, but certification also created a set of standards that reduced the need for (costly) mutual adaptation in specifying any later changes that did need to be made. NUMMI thus derived considerable benefit by "front-loading" mutual adaptation, that is, shifting it to earlier phases than the Big Three.

Organization theory provides us with the concepts needed to theorize these effects. Thompson (1967) argued that pooled interdependence is managed through standards, sequential interdependence through plans and schedules, and reciprocal interdependence through mutual adaptation, and that this sequence constitutes a Guttman scale of increasingly effective but increasingly costly coordination mechanisms (see Adler 1995 for application to the different phases of product development). The Big Three's traditional management model assumed that the changeover task could be managed sequentially, relying on standards, plans, and schedules to assure interdepartmental coordination. NUMMI aimed at a higher degree of joint product/process optimization, and they therefore interpreted the changeover task as embodying more uncertainty than the Big Three did. NUMMI therefore used more intensive coordination mechanisms, in particular mutual adjustment. By front-loading this mutual adjustment, NUMMI reduced the number and cost of downstream problems. Compare Big Three practice: according to Chevrolet Engineering Director, Dave Hanson, "One major change in [General Motor's model changeover] strategy this year is an emphasis on validating supplier parts as production-ready during pilot assembly. [..] In the past, GM sometimes forged ahead to regular production when fewer than half a vehicle's parts had been validated at pilot" (*Automotive News,* Oct. 1994).

NUMMI's tradeoff position was further improved by distinctive capabilities in the upstream departments. The coordination and integration of all the units involved in the model changeover was greatly facilitated by the fact that Toyota designers and design engineers were far more sensitive to manufacturability concerns than their Big Three counterparts. They all began their employment at Toyota working on the assembly line for a period; their managers accorded manufacturability assurance a high priority throughout the design cycle; and Toyota design engineers had accumulated a considerable body of both tacit and codified manufacturability knowledge (see also Clark and Fujimoto 1991). The resulting knowledge gave design engineers tacit and explicit manufacturability standards with which to guide their work, and thus reduced the number of issues requiring mutual adaptation discussions with manufacturing personnel. This background assured both goal congruence across functions and unusually high levels of competence in this part of the design engineers' task.

The Pilot Team

One of the most striking differences between the traditional Big Three approach and NUMMI's was the role that production workers played in the design of NUMMI's products and production processes. One Team Leader from each group in the plant was selected to join a Pilot Team. Their primary responsibility was to draft the standardized work sheets and to train supervisors and workers in their new jobs. They also worked hand-in-hand with the engineering changeover team, helping to fine-tune the product design, select equipment, and lay out the production process.

The Pilot Team at NUMMI was a permanent unit with rotating membership. Its role and size changed depending on the schedule of model changes. Workers joined the team for months at a time, usually returning to the shop floor when the model they were preparing moved into production. Eight months prior to the start of production, the Pilot Team consisted of eight members; three of them had worked on the previous major model change in 1988, while the others had only been through the minor model change of 1991. Within two months, the Pilot Team had added 16 new members. By the start of production, there was a total of two Group Leaders and 32 Pilot Team Members.

Pilot Team members were given a lot of informal on-the-job training, and they had a considerable body of documentation from prior model change projects, including Pilot Team activity flow charts. Formal training in their new task, however, was minimal. Their work involved considerable improvisation—a degree of improvisation that contrasted strongly in their minds with the structured quality of regular line work. One Team Member described the relatively organic form of their organization in these terms: "The first day, I thought, 'Okay, I'm on the Pilot Team now. I've got a desk.' But there were no instructions. It was a crash course for us. We just kind of figured things out."

The Pilot Team was divided into groups representing the different sections of the plant (bodyweld, paint, assembly, etc.). Functioning in a matrix structure, each group cooperated closely on the one hand with staff engineers under the engineering section's assistant manager, and on the other hand with the Group Leaders responsible for the corresponding section of ongoing production operations. Through the first of the two major pilot runs, each section's Pilot Team Leader reported primarily to the Engineering department manager, and from then on they reported primarily to the relevant section manager in Production.

Early in 1992, seven months before the start of production, the Pilot Team traveled to Japan to study the Takaoka plant. (Recall that the earlier NUMMI visits had been by the engineering team and suppliers.) They took with them concerns and suggestions for improvements collected from Team Members in their areas. The Pilot Team members worked on the Takaoka line to learn how their counterparts had designed the specific jobs in the part of the line for which they were responsible. When they returned from Japan, the Pilot Team brought with them large binders containing illustrations of individual parts and explanations of how they should be assembled. They then experimented in NUMMI's pilot area—an area set aside in an unused part of the plant—modifying this documentation to fit the specifics of NUMMI's line, and turning it into detailed draft work instructions (standardized work sheets) for production Team Members. They also worked with their staff engineering partners to design and source the appropriate equipment for each job.

During their time in Japan as well as during their continuing efforts at NUMMI, the Pilot Team and the engineers not only refined the process design, they also proposed product design modifications. Although some design change proposals were rejected as too expensive, most were incorporated. Design changes were particularly numerous for the Prizm. The Prizm was sold by GM, and GM had exercised its right to make design changes to the Toyota vehicle on which it was modeled (a car sold in Japan as the Sprinter). The NUMMI Pilot Team's input was particularly important on the Prizm as they were the first to assemble the modified design of the car. Many suggestions aimed to make the cars easier to manufacture, while others improved its cost and quality.

Relative to traditional U.S. practice, the Pilot Team was a novel partition, facilitating mutual adjustment both between process design considerations and production realities, and between process design and product design considerations. By contrast, the traditional Big Three sequential approach lacked cost-effective ways of dealing with these issues. First, when the product specifications were released to Big Three staff industrial engineers, they worked from handbooks and computer models—rather than from real production conditions—to define processes, layouts, and methods. Pilot production was traditionally conducted on special pilot lines located not in the final assembly plants that would ultimately produce the car, but in special facilities, such as low-volume limousine plants, where pilot production would be less disruptive to ongoing operations and geographically closer to central engineering staffs. These pilots were not controlled by plant personnel, but by staff engineers who did not normally work in the manufacturing plants. The manufacturing plant would conduct its own trials only after it had shut down for the changeover. And the new product and process design would only be tested in real production conditions when workers returned to work at the resumption of operations.

Moreover, whereas the Pilot Team could rely on collaborative mutual adjustment with other participating units, Big Three design engineers traditionally did not actively participate in manufacturability improvement efforts. (We should note again, however, that this pattern has been changing in recent years.) Once the design had been thrown over the wall to the manufacturing staff, it was very difficult to get Big Three designers and engineers to review, let alone approve, manufacturability-motivated Engineering Change requests. Even if a design change proposal was eventually accepted, the average time between submission and release was around six months. Our interviewees at NUMMI described Toyota design engineers as far more actively involved and responsive right through vehicle launch.

Working with Suppliers

Under the traditional Big Three approach, the auto company's relationships with outside suppliers were arm's length and often adversarial. If one supplier had rising costs or declining quality, the auto company could quickly switch to another. To maintain the credible threat that a relationship could be easily terminated, the auto company employed several suppliers for each part and negotiated only short-term contracts. While this strategy maximized the auto company's bargaining power, it also required it to perform the design work in-house, and thus cut it off from suppliers' ideas about product design and limited suppliers' customer-specific investment (Helper and Levine 1992, Helper 1990).

NUMMI, following Toyota, took a very different approach. Prioritizing the ability to harness suppliers' innovative capabilities and to fine-tune part designs, NUMMI usually kept only one or two suppliers per part, negotiated long-term contracts with them, challenged them to make product and process improvements, and worked with them when problems arose. In preparation for the '93 model, engineers from major suppliers worked in the NUMMI plant throughout 1992, just as Japanese suppliers had worked with the Toyota design team the previous year.

However, the transition from the old adversarial approach was not easy for many suppliers. They were not accustomed to Toyota's high standards for quality, timeliness, and cost, nor to the expectation of continuous improvement, nor to the collaboration NUMMI offered to improve their performance. In the 1993 model change, the challenge of transforming the supplier base and developing new supplier relations was exacerbated by a significant jump in the proportion of NUMMI's parts that were made in North America. In 1992, NUMMI's cars used parts from 88 domestic suppliers and had a domestic content of 63 percent (using the Environmental Protection Agency's Corporate Average Fuel Economy metric); the 1993 models used parts from 124 North American suppliers and had a domestic content of 75 percent.

Some suppliers had participated in both NUMMI and Big Three changeovers, and their experiences were very different. Apart from the differences already noted, the general manager of one of NUMMI's suppliers identified several others:

> NUMMI and Toyota have a detailed "template" for the process—a master schedule—and they follow that schedule very closely. It's the same template from project to project, with only minor variations depending on the complexity of the product and what they've learned from the previous project. We also supply parts to GM, but at GM the process changes from project to project.
>
> Toyota puts a lot of effort into prototyping and pilots, and that reduces the number of engineering changes after they issue production drawings. In the GM system, many suppliers make low-ball bids to get the business because they count on a whole lot of engineering changes to make their profit. Toyota focuses more on the details earlier in the process. They use the pilots to discover every possible problem and solve them. At GM they use pilots to "confirm" what they think they already know, not to uncover what they don't know.

These differences in supplier relations echo those we have noted in relations between internal units. NUMMI front-loaded more mutual adaptation with the aim of minimizing the need for downstream interaction; NUMMI facilitated this front-end mutual adaptation by collaborative rather than arm's length relations with zero-sum or negative-sum bargaining; NUMMI benefited from a redistribution of tasks across the supplier/assembly partition, relocating some innovation tasks in the supplier firms where they could be performed more knowledgeably; and NUMMI reduced the cost of this mutual adaptation by the use of the metaroutine of a standard master schedule. In organization-theoretic terms, we would say that as a result, NUMMI's supplier relations were more effective at both buffering (to reduce uncertainty in the core) and bridging (to manage remaining uncertainties) (Scott 1992, pp. 193 ff.; Gerwin 1993; Corrêa 1994).

Pilot Production

Five months prior to the start of production, NUMMI workers built the first set of 25 pilot vehicles. This first pilot build focused on engineering issues. It was therefore conducted off-line in the pilot area, and it relied primarily on parts that were custom-built by suppliers.

In June 1992, two months before start of production, the second major pilot build was conducted. Whereas the first pilot focused on engineering issues, this one focused on production issues. It was conducted on the regular assembly line, and primarily used parts from suppliers' regular production lines.

Because of the mixed-model discipline in its regular operations, NUMMI could intersperse this second set of pilot vehicles with regular production vehicles, leaving just two empty spaces in the production sequence to signal the arrival of the pilot vehicle. This represented a remarkable degree of agility, since all the associated parts and equipment had to be in place along the line, and workers had to be able to switch between the two sets of parts and tools in the 120 seconds afforded by the two empty spaces. The benefits of a pilot run on the regular production line with regular production workers were immense: far more problems could be identified than was possible in an off-line pilot build.

NUMMI's management of its pilots offers three salient contrasts with traditional Big Three practice (see also Clark et al. 1992). First, Big Three plants typically did not do on-line pilots in already-functioning plants; they waited until after the old line had shut down and the new equipment had been put into place. This considerably delayed identifying and solving problems. Second, U.S. firms were traditionally guided by cost concerns and were under little pressure to accelerate changeovers; as a result, they laid off most of their production workers during the protracted plant shutdown, recalling them progressively as production accelerated, and training them only as they came back into the plant. Third, these returning workers were trained by the small group of core workers who conducted the first pilot builds, whereas at NUMMI, Group Leaders and Team Leaders had the primary responsibility for training. The Big Three could not use supervisors to do training, since unlike NUMMI, their supervisors were not usually promoted from the shopfloor; they were usually college graduates on a management track, hired straight into supervisory jobs and thus lacking the relevant technical knowledge. And where NUMMI had a Team Leader who functioned as a lead hand for each team, the Big Three generally lacked such a role.

The Acceleration Period

At the cost of some overtime to accommodate training and pilot builds, NUMMI produced a full schedule of the old model vehicle right up to the week before production of the new model began. On August 7, 1992, NUMMI stopped production for one week to prepare for the changeover. During this week, the Pilot Team worked with managers, engineers, and maintenance workers to set up the new line. Production workers were required—as they had been warned a year in advance—to use a week of their vacation time. When operations resumed on August 14, the Team Members returned to new jobs.

To give Team Members time to learn their new jobs and maintain high quality, production volumes were kept very low at first. Instead of producing some 450 cars a shift, Team Members began with four or five cars a shift, trying to work within a 60-second takt time, but taking time out after each cycle to identify the sticking points. ("Takt" is German for meter. Toyota defines takt time as the interval between cars as they leave the line.) As the production process began to flow more smoothly, production volumes slowly increased. Within the first week, the pace quickened from one car an hour to one car every 10 minutes: a single car followed by nine empty slots on the conveyor line. These early vehicles were used to confirm product and process quality.

As had been done during the previous major model change in 1988, management had suspended job rotations temporarily. Rotations were due to restart on September 4, the date when management planned to be producing 140 cars per shift and volume shipments could begin. Management wanted first to ensure high quality at a moderately high production rate before restoring full rotation.

In the first weeks, the primary goal was training. Team Members walked through their jobs, putting on parts, removing them, and putting them on again. The other goal in the first days of production was *kaizen.* Each time the pace increased, new problems appeared: some jobs that had appeared easy at low volume were seen to be overloaded, and new technical issues surfaced. In addition to learning their jobs, workers were also expected to improve them. Nearly every worker we interviewed described suggestions they had made during the first days of the acceleration for increasing quality, productivity, or safety. Most of these suggestions had been tested and implemented very rapidly.

By contrast, the traditional Big Three accelerations were significantly handicapped by the gaps in knowledge and conflicts of interests that marked the relationship between workers on the one hand and industrial engineers and managers on the other. First, going into the resumption of operations, the layout, methods, and line balance defined by industrial engineers were further from the optimum than at NUMMI: industrial engineers worked from theoretical models rather than plant experience, and so their estimates were typically less accurate than the Pilot Team's. Second, the fine-tuning required after resumption of operations was a kind of purgatory, where workers tried to hide under-burdened jobs and foremen tried to locate and add tasks to those jobs, while other workers had to sabotage production to get foremen to relieve impossibly overburdened jobs. And finally, nowhere in all this conflict was any attention paid to fine-tuning the individual worker's work methods: industrial engineers specified the theoretically optimal methods, but in practice foremen left workers to improvise whatever methods would allow them to meet the time standards.

Problems in the Acceleration

The new line took only 77 days to accelerate to full production. This was far faster than typically found in Big Three plants, but not as fast as NUMMI's original plan of 60 days. The acceleration had to surmount three sets of unanticipated problems. First, some of the new technology introduced with this model change—notably, a doors-off conveyor and an instrument panel sub-assembly line—broke down more often than expected. Second, some parts did not arrive on time. NUMMI had changed some of its supply logistics, consolidating some deliveries in Chicago and taking more frequent deliveries; errors in planning and executing these changes led to delivery delays. Third, numerous part-fitting and "workability" problems appeared, partly because of weaknesses in some US suppliers (see for example, Bowen and Ryckebusch 1996, p. 13), and partly because some US suppliers were working to outdated drawings supplied by their Japanese counterparts. Working in close collaboration back in Japan, Toyota engineers and Japanese suppliers had made numerous fine-tuning changes to parts designs, but often they failed to update the corresponding drawings sent to US suppliers.

The plant was able to maintain high quality, but these workability problems imposed a considerable cost. Productivity suffered as parts that should have taken five seconds to snap into place took 10 or 15 seconds. That difference, while seemingly small, can require that the line be stopped repeatedly, and NUMMI lost about $9,000 in revenue every minute the line stopped.

Workability deficiencies not only hurt productivity; they also hurt workers. When parts did not fit well, NUMMI workers tried to force them into place. During the acceleration, management and union officials alike reported seeing workers pounding parts with the palms of their hands. The stresses these actions place on the body can lead to soft-tissue disorders such as tendinitis and carpal tunnel syndrome. According to the OSHA-200 log, NUMMI's injury rate jumped in the first month of production to a level some 50 percent above that of the prior year.

A month after the resumption of operations, in response to the growing number of ergonomic problems, the union demanded that rotation be restarted. Redesigning the relevant parts would take time, and the union's position was that in the interim, ergonomic strains could be relieved by resuming rotations for the most stressful jobs. NUMMI management refused, arguing that short of aborting the launch, it was physically impossible to free up enough people to allow the cross-training that would be needed for rotation. On September 28, 1992, the UAW Local filed a formal complaint with Cal-OSHA. A few weeks later Cal-OSHA began an investigation, and the following January, Cal-OSHA issued one warning and two "serious" citations based on a large number of ergonomic problems that the OSHA inspector observed in the passenger car assembly area. NUMMI appealed the two citations. In January 1994 a settlement was reached with OSHA committing NUMMI to more substantial efforts in the ergonomics arena, and later that year a new ergonomics agreement was reached with the UAW creating a full-time union ergonomics representative. (On this ergonomics conflict, see Adler et al. 1997).

Results of the 1993 Changeover

The 1993 model change was a very smooth process compared to the traditional performance of Big Three plants. Within five months of the start of production, assembly efficiency was up to 96 percent, which was two percent over target, and two percent over the level a year earlier. These levels are all the more impressive given that assembly efficiency was measured as the ratio of actual daily output to scheduled output, and the scheduled output implied 100% utilization with no line downtime allowance built in. The influential J. D. Powers ratings—based on customers' evaluations of vehicles produced in the last three months of 1992, that is, just as NUMMI was accelerating production—showed only a three-point slip in the number of defects per 100 NUMMI Corollas and a two-point slip per 100 Geo Prizms. That is, the average number of defects a typical car owner identified in the first three months of ownership rose by 0.03 and 0.02 respectively. This minor dip left NUMMI's passenger cars still ranked first and second among all small cars produced in the US.

While these results were impressive, the 1993 model introduction was not completely successful. As a result of the problems encountered in NUMMI's 1993 model introduction, the plant reached full production after 77 production days instead of the planned 60 days. The total shortfall in output over this acceleration period was about 3,500 cars. Although this was less than a week's production, it took many weeks of overtime to make it up.

Moreover, scores of workers were injured, some perhaps permanently. The conflict over ergonomics also contributed to a degradation of labor-management relations. In the 1994 union Local elections, the more confrontational People's Caucus won an almost clean sweep, taking all but the President's position from the more cooperative Administrative Caucus. The reasons for this shift within the Local were complex, but according to many interviewees it reflected a need felt by the rank and file for a more assertive union voice. Later that year, NUMMI experienced its first work stoppage, a two-hour walkout during the contract negotiations. (We should note, however, that the broader pattern of union-management cooperation was not much affected by this change and that the Administration Caucus took back leadership of the Local in the 1997 elections.)

The 1995 Truck Launch

Two years after the 1993 passenger car line changeover, NUMMI made its next major model change, this time the introduction of the Tacoma compact pickup truck. The contrast between the two changeovers was striking: whereas the 1993 changeover had taken 77 days to reach full production, the comparably complex changeover on the truck line took only 48 days.

Moreover, the health and safety conditions of this changeover were far superior. The first three months of a new model launch usually have above-average injury rates; nevertheless, in the first three months of the Tacoma launch, the truck area reported nearly 30 percent fewer injuries than during the same period in the prior year, and fewer than on the passenger line at the same time. This was a particularly impressive accomplishment, since in prior years, the truck line had a worse health and safety record than the passenger line. In this section, we analyze the reasons for these contrasting outcomes.

The "Reflection-Review"

Following Toyota policy, NUMMI conducted a "reflection-review" (*hansei*) soon after the 1993 model passenger line reached full production. Before memories had time to fade, top management, section managers, Assistant Managers, Group Leaders, and Pilot Team members documented the lessons learned from the launch.

Changeover project teams at NUMMI relied on a considerable body of documentation in voluminous binders representing the accumulated lessons learned from prior experience. The *hansei* process allowed NUMMI to progressively refine these procedures. One interviewee explained the process in these terms:

> The binders give us best-practice procedures for managing model changes—just like standardized work sheets give the worker best-practice procedures in regular production. And the learning process is the same. In manufacturing, anomalies show up as differences between takt time and the worker's actual cycle time, and these anomalies lead to problem-solving, which then leads to defining counter-measures, which in turn leads to new standardized work procedures. Anomalies in the changeover process are the differences between our target changeover time and our actual time. The *hansei* process is simply the problem-solving procedure we use to improve our model change process.

As in previous reflection-reviews, vice president of Manufacturing and Engineering, Gary Convis, gave the section managers six weeks to prepare their analyses, then conducted a plant-wide meeting with all the General Managers, Assistant General Managers, Managers, and some Assistant Managers to review each section's summary report. Over the following few days, Convis met with each section—Managers, Assistant Managers, and Pilot Team members—to review the binders and summaries. In these multi-level forums, there was little opportunity to hide deficiencies, and senior management encouraged a norm of fact-based, critical scrutiny with the goal of identifying improvement opportunities for the next project.

The review of the 1993 changeover identified scores of such opportunities in every facet of changeover management. In particular, it highlighted the need for greater focus on ergonomic issues. This led plant management to accord a high priority to health and safety in both the company's strategic plan and the planning for the Tacoma truck launch. The goal NUMMI set for 1995 was to cut the overall plant injury rate by 30 percent.

The Pilot Team and Workability

One of the lessons learned from the 1993 changeover was the need for greater staffing continuity and depth of expertise in the Pilot Team. Organizational memory needed to be deployed not only through the formal mechanism of documentation but also through informal mechanism of team composition. As a result, most of the workers selected for the Tacoma Pilot Team had worked on one or more major model changes.

Unlike the 1993 changeover, the Tacoma Pilot Team members were told that ergonomics was a key objective and they were given extensive ergonomics training. The truck line's poor health and safety record was in considerable measure due to inadequate attention to ease of assembly in the earlier trucks' designs. As a result of the combined efforts of Toyota and NUMMI engineers and the Pilot Team, the Tacoma was far easier to assemble than its predecessors.

NUMMI's Quality engineers also put more emphasis on workability issues than in the 1993 case. They spent more time analyzing parts before and after each pilot. The Quality Engineering department also established better communications with suppliers, and suppliers in turn were able to respond more rapidly to design changes. NUMMI and the Toyota Supplier Support Center (based in Lexington, Kentucky) provided technical assistance to suppliers whose parts had caused problems in the 1993 changeover.

Training and Rotation

Unlike NUMMI's earlier changeovers, the policy in 1995 was to ensure that all Team Members rotated between at least two jobs from the very first vehicle. The explicit goal was to make full rotation the standard policy for the entire truck and passenger lines.

In the Tacoma changeover, Team Member training was therefore accorded a very high priority. Training on paid overtime was made mandatory, whereas for the 1993 launch overtime for training was at the Team Members' discretion. Although freeing up training time was difficult because of the high demand for the outgoing model truck, within a month of the start of production, virtually every team was able to rotate workers between four jobs.

Resumption of Operations

Responding to the experience of the 1993 launch and anticipating unforeseen problems and the weeks and months that would be needed before *kaizen* activity would bring headcount back down to steady-state levels, NUMMI hired 20 extra employees. Whereas in 1992, Team Members took a week of vacation time during the changeover, NUMMI asked truck line Team Members to work over the Christmas/New Year break just before production began to facilitate *kaizen*, training, and preparation.

Within two months of the resumption of operations, the plant was well head of its production goals. Partly as a result of some training shortfalls, quality had suffered somewhat during the acceleration period; but within four months it had reached a world-class level comparable to that achieved by the truck line's sister plant in Japan (Hino).

Safety Awareness

The higher priority accorded ergonomic issues during the Tacoma launch reflected changes introduced in the wake of the Cal-OSHA citations. Management had made safety improvement a strategic priority, and had tied managers' evaluations and rewards to their departments' safety record. Some of the new policies may not yet have born all their fruit, but as of mid-1995, both the truck line and the plant as a whole were on target to achieving the strategic goal of a 30 percent reduction in the injury rate.

Discussion

Organization theory suggests that an organization producing hundreds of thousands of nearly identical products each year should be a machine-like bureaucracy with extensive formalization, standardization, hierarchy, specialization, and staffs. NUMMI's regular operations appeared to fit these descriptors. Yet NUMMI was also remarkably agile in responding to the challenge of major model changes, a challenge that calls for a more organic form of organization. The organization of NUMMI's changeovers appears to fit this description too. NUMMI appears to have been able to have it both ways. Instead of being stuck in the middle, weighed down by the conflicting requirements of efficiency and flexibility, NUMMI seemed able to excel simultaneously in both dimensions. Moreover, NUMMI was able to further shift the tradeoff frontier by improvements both in efficiency and changeover agility between 1993 and 1995.

Mechanisms and Impediments

The resolution of this apparent paradox lies in NUMMI's successful deployment of the four mechanisms we identified in the prior literature. First, the metaroutines of standardized problem-solving, changeover process procedures, and the reflection-review process allowed NUMMI to significantly routinize otherwise nonroutine tasks associated with changeovers, and thereby to improve efficiency without impairing flexibility and vice versa. Second, NUMMI enriched routine production work, encouraging and training line employees and suppliers to stay alert for improvement opportunities. Third, workers switched easily between routine production roles and nonroutine *kaizen* roles in quality circles, in pilot runs, and in temporary assignments to the Pilot Team. Fourth, NUMMI used partitioning more effectively than traditional approaches allowed: it created a new, relatively organic partition, the Pilot Team, devoted to the nonroutine tasks associated with changeovers; it allocated tasks more effectively across existing make/buy partitions; it eliminated dysfunctional partitions such as the methods engineering department; and it greatly improved coordination and integration between partitions. NUMMI could thus enjoy the benefits of both discipline and creativity.

Organizational theory reviewed above predicts a number of potential impediments to such mechanisms: How did NUMMI overcome them? We can summarize the lessons of the NUMMI case by reviewing the four mechanisms in turn and summarizing NUMMI's approach to each.

First, some strands of theory predict that the routinization of nonroutine activities will lead either to resistance to modifying routines by employees anxious to preserve the *status quo* or to resistance to the use of routines by employees anxious to preserve their task autonomy and variety. NUMMI avoided resistance to the modification of routines with a strong culture of *kaizen*, rewards for innovation, and strong leadership to reinforce that culture. NUMMI overcame resistance to standardization by involving the employees themselves in the development and refinement of these routines. Instead of staff methods engineers imposing formalized standards on core employees, workers participated actively in defining and refining standardized work sheets. Instead of staff experts imposing changeover management procedures, the entire organization used the reflection-review process to progressively define and refine the procedures.

NUMMI appeared to have largely overcome resistance to relinquishing autonomy and variety in core tasks through two complementary means. First, when workers participated in the effort to routinize their core tasks, participation in this activity increased autonomy and variety, albeit only very modestly and in a noncore task, and thus at least partly addressed workers' demands for more meaningful work. Second, this fundamental limitation on motivating job characteristics was legitimized in the eyes of NUMMI workers. Routinization was not imposed on workers but presented as the path to competitiveness—and job security—in the world of high volume, mass production.

Second, some theory argues that enriching workers' jobs in mass production activities such as auto assembly will require inefficient levels of training, and that the job enlargement commonly recommended to accompany job enrichment will weaken the discipline required for efficiency in routine core tasks. NUMMI overcame the former impediment by a complementary investment in support for worker *kaizen* activities: in combination, these two investments generated large returns in the form of a very large number of worthwhile, albeit typically small-scale, improvements. This support was in the form of *kaizen* training, job rotation to broaden workers' understanding of the production system, engineering support for the timely testing and implementation of workers' suggestions, and strong management support for worker suggestions. This suggests that the returns to investments in worker training may be low or negative until a certain threshold is reached and an integrated package of management practices creates structures, incentives, and ability for continuous improvement (Levine 1995). The second possible impediment to enrichment as a tradeoff-shifting mechanism is the loss of discipline in the implementation of standardized procedures for routine tasks that comes with excessive lengthening of cycle times. NUMMI avoided this problem by keeping the cycle times for core production tasks very short and putting great stress on the value of standardized sequences of motions in assuring high productivity and quality. A related potential impediment lies in the additional risk of opportunism created when enrichment reduces task programmability. NUMMI appears to have avoided this class of problems through the establishment of a high level of mutual trust between workers and managers: trust in competence and goal congruence.

Third, some theory predicts that allowing employees to switch roles sequentially will not significantly shift the efficiency/flexibility tradeoff since workers can hardly function as respected problem-solvers in organically structured quality circles and improvement teams if they are treated as closely monitored proto-robots in their repetitive jobs during the rest of the week. NUMMI appears to have overcome this impediment by an extensive set of policies and practices that encouraged innovation and employee involvement, including a participative leadership style in routine production, worker involvement in defining and refining work procedures, a team-based work design, a commitment to employment security, a union that ensured management kept its commitments, and gainsharing.

Fourth, some theory is skeptical of the partitioning mechanism's ability to shift the tradeoff because the creation of new subunits typically creates additional management overhead for coordinating and resolving conflicts between subunits. Several factors reduced the coordination and integration costs associated with the creation of the Pilot Team. First, the Pilot Team was drawn from among the production Team Leaders and the assignment was only temporary. This reduced potential gaps in knowledge, values, and incentives. Second, coordination costs were reduced by ensuring that the Pilot Team worked in close interaction with the line organization all through the changeover process. The Pilot Team was matrixed into line management and it was located in the plant. Very early in the preparation process, line workers identified for the Pilot Team problems with the current process that they wanted to see fixed. Later in the process, during off-line training and on-line pilots, line workers contributed *kaizen* ideas. And on-line pilot production multiplied these interaction opportunities. The same principles governed the role played by suppliers in the changeover process: their involvement, cooperation, and extended on-site visits to the plant early in the changeover process enabled NUMMI to simplify the downstream changeover task.

Our narrative revealed that NUMMI was not always successful in its efforts to shift the tradeoff to combine faster changeovers with greater efficiency. First, some improvements to flexibility were bought with slack and the associated loss of efficiency, most notably the decision to hire an additional 20 workers for the 1995 changeover. This decision appears to have been simply an adjustment, probably a wise one, to NUMMI's position on the existing tradeoff curve. Second, NUMMI stumbled in the 1993 changeover when management failed to provide enough ergonomics expertise and failed to maintain the appropriate balance between production and safety goals. It stumbled too, in the 1993 logistics bottlenecks. However, from the points of view of both workers and business performance, NUMMI was able to learn from these failures, as evidenced by simultaneous improvements in flexibility, efficiency, and health outcomes in the 1995 changeover.

Training and Trust

Training and trust appear to be the critical contextual factors determining the effectiveness of these mechanisms' implementation at NUMMI. We have already commented on training of production workers, and our narrative also revealed the importance of "technical support" for NUMMI's suppliers, which was mainly in the form of training. The traditional Big Three model of supplier relations was based on a cost-minimization strategy; it promised a form of flexibility too: in the ease of switching between suppliers. But functioning in an arm's length mode, this model cut the auto assembler off from potential design and efficiency improvements that suppliers could be induced to make if they saw the assembler as a long-term partner.

Trust appears to have been a second critical contextual factor. Consistency, competence, and congruence trust were key in assuring support for and effective use of metaroutinization, enrichment, switching, and partitioning mechanisms. If trust levels between units, layers, and suppliers were not high, all four tradeoff-shifting mechanisms would have been hobbled. Workers' trust in management was challenged when the 1993 model changeover began creating high levels of ergonomic strain for many workers, leading to a confrontation with the union and citations by Cal-OSHA. The basic fabric of trust was, however, largely restored when—under the combined pressure of top management, Cal-OSHA, and the union—management changed its approach in the 1995 truck-line model changeover. New ergonomic assessment procedures were put into place, bolstering consistency trust. Ergonomics training was increased, increasing competence trust. And health and safety became a company strategic priority, significantly restoring congruence trust.

In our description of NUMMI's organizational structure, we highlighted the distinctive form of bureaucracy that characterized its routine operations, a form that has been characterized as "enabling" in contrast with the more commonly-encountered "coercive" form (Adler and Borys 1996). Our analysis of ambidexterity at NUMMI reveals a strong link between this enabling form of bureaucracy and trust. Trust is often seen as an alternative to bureaucracy and its rules; but as Sitkin (1995) has argued, this is only true if formalized rules ("legalization" in Sitkin's study) are "viewed as a 'people-proofing' substitute for relational trust," and in this case bureaucracy will indeed tend to undermine trust. However, if "formal procedures and standards are used to routinize repetitive interactions and stabilize expectations," and if the organization follows the "rule of minimization: keep formalized trust simple and narrow in scope," then high levels of bureaucracy can buttress rather than undermine trust (Sitkin 1995, pp. 209–210).

NUMMI appears to support Sitkin's conjecture that organizations can be simultaneously high in trust and high in degree of bureaucracy, and that in such organizations, bureaucracy will take a distinctive form. In a high-trust organization, formalized and standardized procedures do not have to be defined by staff experts and imposed on reluctant subordinates; they can be defined jointly by employees, specialists, and managers. They do not have to serve primarily as mechanisms for coercing effort and compliance from recalcitrant employees; they can serve as the organizational memory of best practice. Horizontal and vertical specialization do not have to segment the organization into rivalrous subunits and antagonistic layers of positional authority; they can facilitate the accumulation of expertise and its optimal distribution, and the specialized units and layers can function collaboratively. And finally, staff units do not have to function in opposition to and domination over employees in the operating core; they can function as support specialists in a partnership and consulting mode. In such organizations, interpersonal trust and "system trust"—trust in the consistency, competence, and congruence of management structures and systems—are complementary rather than substitutes (on system trust and related concepts, see Giddens 1990, Luhman 1979, Zucker 1986, Shapiro 1987).

Our case study also shows that system and interpersonal trust were buttressed by a set of policies that created incentives for management to act *as if* they trusted employees and suppliers, and *as if* they were trustworthy partners. From a psychological point of view, affective trust, whether in individuals or systems, and its calculative cousin are very different; indeed, as Williamson (1993) has argued, "calculative trust" may be a superfluous construct; but the NUMMI case shows how the affective forms of trust, both interpersonal and system, and its calculative forms can function in tandem.

Game theory and common sense suggest that there are long-term costs to short-term opportunism, because over time both parties find it valuable to maintain a reputation for fair dealing. We see this relationship at work in NUMMI's labor and supplier relations. NUMMI's policies of high training and employment security bolstered employees' consistency trust, since they were more confident that NUMMI was in a situation of repeated play. NUMMI (like its parent Toyota) promoted information sharing among its suppliers in a supplier association. The establishment of a mechanism to promote such communication raised the cost to NUMMI of acting uncooperatively with any individual supplier. In both cases, NUMMI bound itself in ways that made trusting and trustworthy behavior more likely to be in its self-interest.

Most subtly, NUMMI bound itself to act in a trustworthy fashion by relying so much on the ideas and commitment of its employees and suppliers. NUMMI knew that short-sighted actions that would destroy trust would also stop both the flow of production and of *kaizen* suggestions. The trust NUMMI exhibited in its workers and suppliers served to establish a gift exchange relationship that bolstered congruence trust at an affective level. In addition, however, this trust also placed NUMMI in a position of dependency. In game-theoretic terms, NUMMI designed its production process so that its need for worker commitment and *kaizen* was a hostage it gave to workers and suppliers. The presence of this implicit hostage made it more likely that workers and suppliers would trust NUMMI to act as if it valued their competence and their goals. Under such circumstances, calculative trust was likely to engender affective trust. In the words of George Nano, Bargaining Committee chair,

> The key to NUMMI's success is that management gave up some of its power, some of its traditional prerogatives. If managers want to motivate workers to contribute and to learn, they have to give up some of their power. If management wants workers to trust them, we need to be 50/50 in making the decision with them. Don't just make the decision and then say, "Trust me." (quoted in Adler 1993, p. 180)

The centrality of trust suggests a typology of organizational forms shown in Exhibit 2. The lower part of the diagram focuses within the organization, and shows that the range of organization design alternatives is not a one-dimensional spectrum from organic to bureaucratic/mechanistic, but rather a two-dimensional matrix contrasting high versus low extent of bureaucracy on one dimension and high versus low levels of trust on the other dimension. The conventional one-dimensional contrast between organic and mechanistic forms appears as a diagonal of this part of the matrix, since it is conventionally assumed that the former will take a high-trust form and the latter a low-trust form. The NUMMI case suggests the possibility of a high-trust, high-bureaucracy configuration. The top row of the matrix suggests that in its relations with other firms, the organization can operate in either high-trust, partnership mode or low-trust, instrumental mode.

On the more conventional view, attempts to shift the efficiency/flexibility tradeoff by combining organic and mechanistic forms within the organization and by mobilizing suppliers risk failure since both approaches try to

Exhibit 2 A Typology of Organizations

		high trust	low trust
suppliers		partners	rivals
firm	low level of bureaucracy	organic	autocratic
	high level of bureaucracy	enabling bureacracy	coercive bureaucracy

mix "oil"—the high-trust, organic, innovation subunits within the firm—with "water"—low-trust relations with external suppliers outside the firm, between the innovative subunits and the bureaucratic core of the firm, and within the bureaucratic core. But the NUMMI case suggests that it is possible to position all the players in the high-trust column of the matrix. This is the heart of the "cultural" transformation required by TQM (Hill 1995). In such a configuration, (partner-) suppliers can be mobilized to support the changeover process's need for mutual adaptation; the (enabling-) bureaucratic core with highly routinized tasks pursuing efficiency can cooperate effectively with (enabling-) organic subunits pursuing innovation and flexibility; employees and managers can switch easily between these two very different kinds of tasks; and metaroutines for accelerating organizational learning can be pursued collaboratively rather than imposed.

Conclusion

Our analysis of NUMMI has revealed it to be an organization that has repeatedly shifted the efficiency/flexibility tradeoff. It had an exceptional capability for both first-order and second-order learning. Four mechanisms made this possible. Metaroutines made nonroutine tasks more routine, with the direct effect of increasing efficiency for given levels of flexibility and the indirect effect of creating opportunities to increase flexibility. The other mechanisms—job enrichment, role switching between improvement tasks and production tasks, and partitioning NUMMI's structure into a changeover team and an operating core—had the converse effects: directly, they increased the organization's capacity for flexibility at a given level of efficiency, and indirectly they created capabilities that served to improve efficiency.

Organization theory suggests important potential impediments to each of these mechanisms, but NUMMI overcame them because its bureaucratic core, its nonroutine components, and its supplier relations were all managed in a high-trust mode. Routines and metaroutines were thus embraced rather than resisted. Organic and bureaucratic structures and roles were integrated rather than opposed. Suppliers were mobilized rather than fended off.

Our contrast of the 1993 and 1995 model introductions shows that an organization can continue over time to move along this tradeoff-shifting vector of development. This is perhaps the greatest challenge for an organization, since there are so many incentives encouraging the organization to veer off this vector and join the ranks of more conventional organizations that privilege one or other priority, either flexibility or efficiency.

Leadership would appear to be the key precondition for such persistence. Without committed leadership, NUMMI could not have made its huge investments in training: investments that paid off only in the longer term and often only in indirect ways. Without that leadership, the pressures for short-term production performance would have become much more salient to lower-level manufacturing managers than the need for flexibility and innovation. Without a leadership that continually reasserted the simultaneous importance of flexibility and efficiency, lower-level managers would have likely slipped into a more autocratic style in relations with subordinates and suppliers, which would have in turn undermined congruence trust.

Given the fundamental role of leadership in maintaining such a development path, future research on ambidexterity might usefully focus on its challenges. In Tushman and O'Reilly's (1997) account, top management's leadership looms large; but NUMMI presents a context rather different from the ones they studied, since at NUMMI leadership was not just a prerogative and responsibility of top management. As a high-trust, unionized firm, the leadership function was somewhat more distributed, and the union shared some of its burdens. And to the extent that NUMMI's ambidexterity relied on high-trust relations with suppliers, leadership in the supplier firms too played a key role. Future research on the leadership challenges of ambidexterity might usefully broaden its focus to include these more complex institutional settings.

Future research should also extend our temporal horizon. Our comparison of traditional Big Three practices with NUMMI practices masks an important evolution over the longer time period. The flexibility/efficiency tradeoff has shifted greatly since the days when Ford's changeover from the Model T to the Model A forced the plant to shut down for six months (Hounshell 1984, pp. 266ff). Future research could usefully focus on delineating the sequence of organizational innovations that have progressively shifted the tradeoff frontier. Some of these innovations lie in the domain of organizational structures and processes, and some in technology; long-term shifts in the broader institutional context may also have played a facilitating role. A better understanding of this history might give us more insight into the prospects for the future evolution of tradeoff-shifting organizations.

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Endnotes

[1]Intriguing parallels to enrichment, switching, and partitioning appear in Maybury-Lewis's (1989) analysis of the three "strategies" by which societies manage incommensurate cultural antimonies: "integration" (read: enrichment), "alternation" (read: temporal segregation, or switching), and "social or spatial segregation" (read: partitioning). A reviewer identified another parallel: if we postulate a homology between shifting a tradeoff to improve performance and dealing with paradoxes to build better theory, our four tradeoff-shifting mechanisms parallel the four generic ways of using paradox identified by Poole and Van de Ven (1989). First, the paradox can be accepted and used constructively: this is what firms do when they accept that routine and nonroutine tasks need to be managed differently and then develop metaroutines that make the latter type of tasks more routine and thus increase their efficiency. Second, the domains of reference can be "spatially" distinguished: this corresponds to partitioning. Third, the domains of reference can be "temporally" distinguished: this corresponds to switching. And finally, new terms can be introduced that change the basic assumptions: this is what enrichment does to the assumption that routine work is essentially mindless.

[2]Even though the flexibility/efficiency tradeoff is usually assumed to apply (in varying degrees) to all forms of flexibility, it is instructive to

position major model changes relative to the various theoretical typologies of flexibility. Using Volberda's (1996) strategy-oriented classification, model changes are a form of operational rather than strategic flexibility, requiring high speed but dealing with only moderate variety. In Sethi and Sethi's (1990) classification of types of operations systems flexibility, model changes are a form of "product" and "process" flexibility, as distinct from routing, volume, and expansion types. In Upton's (1994) framework for characterizing manufacturing flexibility, the *dimensions* of flexibility relevant here are product and process (as distinct from input flexibility); the *frequency* of major model changes for which this flexibility is required is a regular four-yearly cycle; the *range* of the product and process change is moderate, since even though most parts will change, the overall architectures of the product and the process evolve only modestly; the *mobility* required is very high, given that highly compressed schedule that NUMMI targets for model changeovers; and the demand for *uniformity* of product quality during the changeover period is very high.

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