Working paper: 02-043

Just-in-Time in practice at Toyota: Rules-in-Use for building self-diagnostic, adaptive work-systems

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September 2002

Last revised: September 5, 2002

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Denver, Colorado, August 2002

ABSTRACT

This paper asserts that problem identification and problem solving processes can be integrated into work processes by imbedding tests that evaluate system-performance. These tests are imbedded in individual work activities, in the connections that link those who provide a product, service, or information with those who receive it, and in the overall construction of pathways over which products, services, and information take their final form. These tests make it unambiguous when, where, and by whom problem solving is necessary, and, as an integral part of collaborative work, these tests help improve processes and deepens process knowledge, allowing an organization to be increasingly adaptive, both when it experiences operating difficulties and in determining how to exploit best market opportunities. These immediate tests are possible if work designs are specified before work is performed, and these immediate tests have most value if each indication that a problem has occurred is followed immediately by root-cause analysis and structured problem solving.

This paper builds upon observations made in the manufacturing sector to draw lessons applicable to more general management concerns of delegating/task partitioning, coordinating, and task execution. This paper shows how the specific tools of the Toyota Production System ('TPS') such as pull-systems, kanban cards, and andon cords are artifacts of a general, comprehensive approach to managing collaborative work systems that allows frequent, fine-grained problem identification and improvement in overall organizational structure, coordinative mechanisms, and task-performance. Therefore, this paper phrases Toyota's practices in terms of solving problems of work delegation, coordination, and execution.

KEYWORDS

Toyota Production System, Rules-in-Use, organizational design, process improvement

1 INTRODUCTION

In reaction to a race to ‘best practice’ -- as reflected in initiatives such as TQM, JIT, re-engineering, and ‘lean manufacturing’ -- Hayes and Pisano (1994) encouraged managers to re-focus on achieving strategic fit by configuring production systems ‘through a series of interrelated and internally consistent choices [that reflect] the priorities and trade-offs in its competitive situation and strategy’. This had to be grounded in ‘a collection of evolving capabilities … which provide the flexibility needed to embark in new directions’. This admonition fit well in the organizational theory, i.e., Lawrence and Lorsch (1967), and operations management literature, i.e., Skinner (1974), which had encouraged ‘contingent’, ‘focused’ organizational forms. Nelson and Winter (1982) offered that the structures and dynamics of organizational ‘routines’ are discovered iteratively, and writers such as Clark, Hayes, and Wheelwright (1988) and Jaikumar and Bohn (1991) emphasized that improvement and development occurs through problem solving, which, von Hippel (1994), Leonard-Barton (1994), von Hippel and Tyre (1995), and MacDuffie (1997) reminded, was situated with problem solving information localized in terms of time, place, process, and person.

This paper asserts that organizations can develop the capabilities to be highly adaptive -- able to address operational problems as they occur and capitalize on market opportunities as they develop -- by putting in place mechanisms that allow highly situated learning that is both broadly distributed throughout the organization but which also works towards common purpose. A critical element in achieving this capability is designing work -- both that done by individuals and that done by groups, collaboratively -- so that problem-solving based, improvement opportunities are evident quickly and so that these opportunities are exploited rapidly.

This paper is organized in the following fashion. Section 2 explains why Toyota was chosen as a research site, and Section 3 explains the ethnographic approach I used. Section 4 introduces a framework for characterizing collaborative work as complex systems with ‘hierarchical designs levels’, akin to characterizing technical systems as having an overall architecture in which interfaces link components. Section 5 provides illustrations of a Rules-in-Use approach for managing the design, testing-in-operation, and improvement of work-systems. Section 6 discusses the implications of using Rules-in-Use to managing collaborative work.

2 RESEARCH CONTEXT

To study first hand and thereby gain an understanding of the micro-dynamics of process improvement, Toyota and its affiliates were chosen as research sites. Existing links among Toyota's quality, cost, and variety advantages and its workforce management and problem-solving processes -- collectively referred to as the Toyota Production System ('TPS') -- supported this decision. Since the 1960s, Toyota has been more productive than its competitors [Cusumano (1988, 1989)]. Its 'TPS' factories have been operationally different from 'Fordist' and 'pre-Fordist' competitors [Krafcik (1988)]. Indeed, Toyota and its Takaoka plant epitomize 'lean manufacturing' [Womack, Jones, and Roos (1990)].

In 2001, Toyota continued to maintain industry leadership. Consumer Reports rated Toyota models first in four of ten product categories. In a separate 2001 study of initial quality, J.D. Power and Associates rated Toyota and Lexus products first in 7 of 16 product categories. Toyota's Kyushu car plant was rated the best in the world, with Toyota's Tahara car plant second in Asia and the Kyushu truck plant third. In North America, Toyota's Cambridge Ontario plant was first, and the Georgetown Kentucky truck plant tied for second. Despite industry-wide difficulties, Toyota's market share and capitalization continued to grow [Burt and Ibison (2001a, b, c)]. Worker involving, problem-solving processes at the NUMMI plant, specifically, a TPS-managed joint venture with General Motors, were a source of performance superiority [Adler and co-authors (1993a, 1993b, 1997)].

2.1 THE LITERATURE'S EXPLANATIONS OF TOYOTA'S OPERATIONS BASED ADVANTAGE

To explain Toyota's performance advantages, much focus has been on Toyota's Just-in-Time tools such as kanban-card paced pull systems, frequent, small batch production and delivery, and reduced inventories. For instance, Hopp and Spearman (2000) have contrasted ConWIP and kanban control of production flows. Deleersnyder et al (1989) and Lee (1989) have compared the relative efficacy of push and pull approaches for production.

In contrast, Adler (1993), Adler and Cole (1993), and Adler, Goldoftas, and Levine (1997) have focused on Toyota's work practices and have emphasized the role of workers in solving production-related problems. Thus they are positioned more closely to writers such as Hayes and Wheelwright (1984) and Clark, Hayes, and Wheelwright (1988) who emphasize the 'microinfrastructural' elements of operations management such as measurement and control systems, workforce policies, management selection and development policies, and organizational structure, and MacDuffie (1997), who has focused on human resource practices and problem solving. Thus, this latter group is more aligned with administrative theory that is concerned with delegation, coordination, and problem solving. This literature has a history tracing back to Weber, Taylor, Barnard, and Drucker and that more recently describes organizations in terms of routines, such as Nelson and Winter (1982) or dynamic capabilities, such as Teece and Pisano (1994).

2.2 RULES-BASED, ADAPTIVE ROUTINES AS THE SOURCE OF TOYOTA'S ADVANTAGE

The field research reported in this paper leads to the conclusion that Toyota has developed a powerful 'dynamic capability' in the form of consistently practiced 'Rules-in-Use' for organizational design, improvement, and adaptation. I discovered that in TPS-managed organizations, [tending to] all work is executed as hypothesis testing experiments that contribute to accelerated generation and accumulation of individual and organizational learning about delegating, coordinating, and performing work done collaboratively. This includes work that is done repetitively and that which is done a few times only.

This discovery adds to the literature most immediately by explaining that the production tools that have received so much attention in the operations research literature are artifacts of these fundamental 'Rules-in-Use' routines, and by explaining the organizational structure and dynamics in which Toyota's continuous improvement occur. More broadly, it provides actionable principles for designing systems that are quick to detect problems in their design as a precursor to rapid improvement and adaptation.

3 METHODS

Many scholars argue that, as a prerequisite to building inductive theories of how processes truly operate, observation and participation must be used to study complex social systems. Ethnographic methods, for example, have been used to articulate social structure and dynamics in situations such as an immigrant Boston neighborhood [Whyte (1993)], religious communities [Heilman (1984, 1992)], and medical practices [Barley (1986, 1990)]. Classic works, such as those by Barnard (1938), Roethlisberger (1942), and Parker-Follet (1940), were deeply grounded in each author's self-reflective participation or intense, close-hand, sustained observation.

As previously discussed, Toyota consistently outperformed competitors, even though it had been open to them, and they had tried to emulate Toyota.[1] This not only suggested that Toyota's management processes had not yet been fully characterized but made ethnographic methods appropriate for understanding the phenomenon of work-system management in greater detail.

To learn how various work systems actually operated, for 176 days during June 1995 to May 1999, I gathered data by doing or observing work across functional specialties at several different organizational levels. My involvement covered a variety of technical processes at different supply-chain stages and in different product-markets across 33 sites in North America and Japan. For five months, I was one of a four-member Toyota team implementing TPS on the shop floor at a supplier. I gathered additional data at Toyota's Tsutsumi, Takaoka, Kyushu, Georgetown Kentucky, Princeton Indiana, and NUMMI assembly plants, and the Kamigo engine plant. Others sites included six Toyota suppliers in Japan and six in North America at differing stages of TPS mastery. To further avoid 'sampling on a dependent variable', I gathered data at non-Toyota sites as well. This included actually working on the assembly line at a non-Toyota plant for one week and observing work at several other plants not affiliated with Toyota.

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[1] Toyota's Georgetown plant has had hundreds of thousands of visitors, and competitors have done major benchmarking studies (Source: Toyota). Chrysler's Operating System (COS) was meant to emulate TPS (Source: Chrysler manager who helped develop COS and deployed it at two plants). General Motors has had the NUMMI joint venture with Toyota since 1984. (Source: http://www.nummi.com.), and modeled its Global Manufacturing System ('GMS') on TPS, according to an authority deeply involved in developing GMS.

For validity, I followed the guidelines for grounded, theory-building research developed by Strauss and Corbin (1990) and Yin (1994). I visited work sites with and worked under the supervision of members of Toyota's Operations Management Consulting Division ('OMCD') and the Toyota Supplier Support Center ('TSSC'). These groups are tasked with developing TPS expertise at Toyota and supplier plants in Japan and North America, respectively. I kept journals that ultimately totaled thousands of pages of daily narratives, material and information flows, ethnographs, and other diagrams and illustrations.

Highly detailed documentation of how systems actually operated, across the multiple dimensions of product, process, function, etc., mentioned above, protected the data and analysis from becoming overly subjective. Analysis was not based on recalling impressions that had faded with time. Rather, detailed, written documentation allowed me to determine what features were context-specific and what were generally characteristic of high-performing systems. Furthermore, I sought to discern consistent patterns in my data, such as what were or were not good applications of 'TPS thinking'. I made these determinations in conjunction with the Toyota staff with whom I worked and who are mentioned above, and through frequent reviews with colleagues. I did this to ensure that both the Toyota staff and my colleagues drew the same conclusions from my data, either on-site while the data were being collected or after the fact with reference to the detailed descriptions I was creating. As my formulations progressed, I predicted work designs before I arrived at plants and used discrepancies between my predictions and actual practice to make refinements. These cycles were methodologically important as deductive tests of the inductively generated frameworks I was developing.

4 CHARACTERIZING COMPLEX WORK SYSTEMS

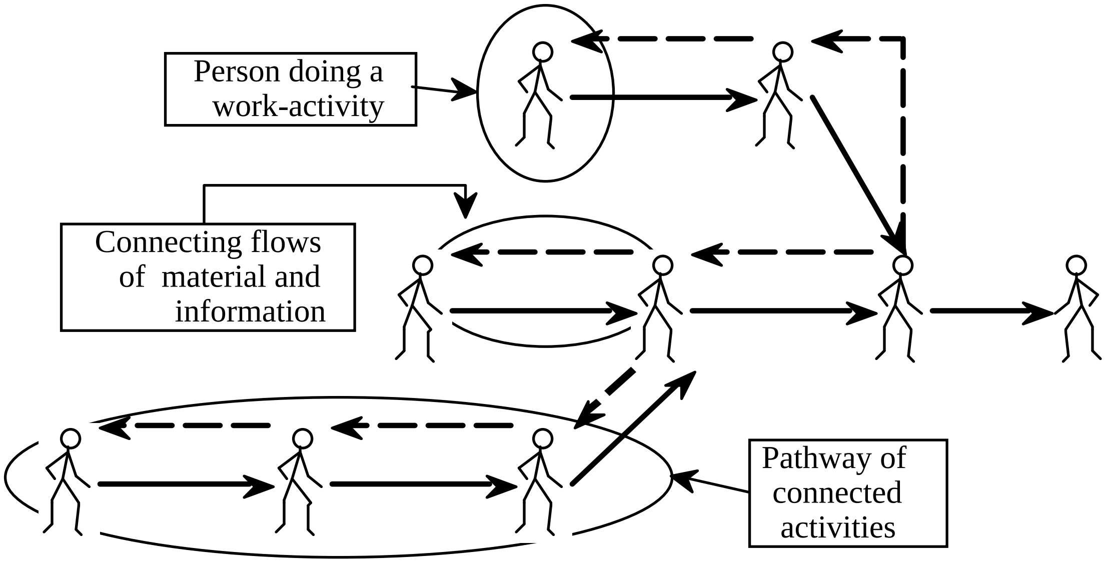
This paper characterizes complex work systems with a framework of hierarchical design levels similar to one used to characterize complex technical systems. Consider a familiar example. A typical personal computer performs a number of functions. Most simply, the system accepts data as input, stores information, performs computations on that data, and generates output in a form valued by the user. In order to create a system capable of performing these basic functions, designers had to make architectural decisions as how to map those functions onto different parts of the system. With early personal computers, the input function was assigned to the keyboard and a disk drive, for instance, data storage was assigned to a hard disk drive, computation to a CPU on a motherboard, and the output function was assigned to monitors and dot-matrix printers. Designers then faced the issue of coupling the various pieces together, so had to make interface decisions, for example creating the serial and parallel port formats for linking computers to printers. Finally, they had to design the individual components of the system, determining how the various printers, monitors, and keyboards would operate. In contrast, modern-day, hand-held computers represent a different set of hierarchical design decisions. The system's value proposition is primarily around portability and convenience, not processing capacity and power. This led to the architectural decision to assign input functions to a touch screen and stylus rather than a higher speed keyboard, storage to flash memory rather than a higher capacity hard disk drive, and computation to a small, relatively inexpensive chip rather than a high end micro-processor. These pieces are linked through interfaces different from the ports characteristic of desktop machines, and the design of the hand-held's components comply with the system, architecture, and interface decisions that have been made previously.

Organizations too can be characterized in terms of hierarchical design levels. At the system level, we ask, what mix and volume of products or services does the organization provide to whom, when? In asking about delegation of responsibility, we are asking an architectural or pathway question by inquiring who provides what intermediate product, service, or information to whom? In asking how those who need a product, service, or information -- whom we will refer to from here as 'customers' -- will receive what they need, and in asking how those who will provide a product, service, or information -- whom we will refer to as 'suppliers' -- will deliver the item, we are asking an interface or connection question. Finally, in asking how individual 'suppliers' will do the work assigned to them, given the way they connect to the rest of the work system, we are asking an work-activity question about the functional components of the organization.

Table 1: Product and Process Design Hierarchies and related questions

Products		Processes/Organizations	
Design Level	Critical questions	Design Level	Critical questions
System	What functions does the system provide for whom?	System	What does the organization produce and deliver (mix, volume, timing) for whom?
Architecture	How is functionality assigned to 'spaces' in the system and how do the spaces relate to each other?	Pathway	Who creates what output (product, service, or information) for whom?
Interfaces	How are the spaces joined together? How do material, information, and energy flow?	Connections	How do customers and suppliers communicate requests and responses?
Components	How do components perform the functions assigned to them given the interfaces they have with the system?	Activities	How do people or machines produce and deliver outputs for which they are responsible given the connections they have with immediate customers and suppliers?

Figure 1: Pathways of connected activities



5 OVERVIEW OF DESIGN SPECIFICATION, TESTING, AND IMPROVEMENT

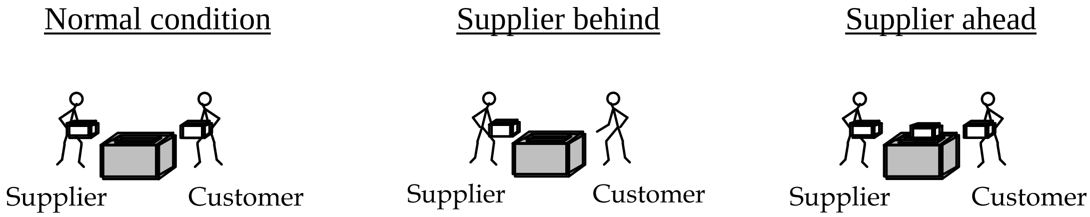
The examples that follow illustrate the distinctive approach I observed taken within Toyota Production System managed organization for designing, operating, and improving activities, connections, and pathways. Because I found that consistency in this approach across products, services, processes, hierarchical levels, stages in the supply chain, functional specialties, industries, markets, and regions, and because similar approaches were not taken elsewhere, I termed these patterns Rules-in-Use and determined that they represented the fundamental essence of the Toyota Production System. This distinctive approach is to (a) specify the design of every pathway, connection, and activity, (b) use built in tests to diagnose with each use every pathway, connection, and activity, and (c) improve pathways, connections, and activities close in time, place, and person to the occurrence of each problem.

This first example is of simple material flow in an assembly process that contributed to this conclusion. The second example is of more complex flows of services and information on an assembly line. These detailed descriptions precede a more comprehensive, but less detailed listing of observations that collectively contributed to the conclusion that 'Rules-in-Use' management provides fine-grain, high frequency diagnostics about an organization's processes. Is responsibility delegated correctly in existing pathways? Are delegated tasks being coordinated correctly using existing connections? Are coordinated activities being performed correctly?

5.1.1 MATERIAL FLOW BETWEEN TWO PEOPLE

This first example is of two people in adjacent locations doing sequential assembly work whom I observed at a Toyota supplier in Japan in July 1997. The space between the two was marked with a single square (Please see Figure 2.) An empty square acted as a request by the customer for the supplier to move one part forward. A part in the square served as a signal not to send another part. This binary 'send -- don't send' signal also provided a built-in-test as to whether the supplier was working faster or slower than his immediate customer actually needed. If the box was empty and the immediate customer had no work, the supplier had fallen behind, and if the box was full and the supplier was ready to deliver another part, his production and delivery rate had exceeded his customer's consumption rate.

Figure 2: Coordinating material flow between two adjacent assembly workers



Normal condition

Supplier behind

Supplier ahead

This simple example illustrates features that were evident in more complex situations also. The customer communicated requests directly to a specific supplier, not through a centralized intermediary, and the supplier responded directly to the customer without deposits and withdrawals of intermediate goods into and out of centralized stores. Requests and responses were ‘binary’; there was a request for a part, or not; there was a correct response or not. The connection between the customer and supplier was self-diagnostic. The supplier’s ‘response’ to the customer’s ‘request’ had both material and information content so that it was immediately evident if their work was or was not synchronized appropriately.

Though simple, this observation was important for the inductive, theory-building process. Elsewhere, I had repeatedly seen kanban cards used to pull small batches of material from specific suppliers, within cells, between cells in a plant, and between plants, and I had developed just such a pull system at a Toyota supplier. These all had common features. Cards traveled within closed, self-diagnostic loops directly linking a particular customer with a particular supplier. Each card acted as a single request for a specific quantity of a specific item, and returned with the item directly from the supplier to the customer as confirmation that the correct response had been generated. When a request could not be filled, the card was placed to signal that a problem had occurred -- i.e., a flag was raised, a light was lit, etc. The observation just reported and others like it were important because precisely the same behavior occurred without using the specific tool. Conversely, the Toyota people with whom I gathered data routinely criticized as ‘poor TPS’ or ‘poor basic thinking’ card-based systems that lacked the characteristics of directness, binary information flow, and self-diagnostics. This too contributed to the realization that the tools that had been the focus of such attention were not necessary elements of ‘good TPS’. Rather, they are among many means of creating similar work-system designs.

5.1.2 CUSTOMER-SUPPLIER CONNECTIONS FOR ASSISTANCE AT TOYOTA PLANTS

The preceding example was of a short pathway and the single connection in that pathway over which a physical product took form. The next example is of a longer pathway, with more connections, over which a service -- problem solving assistance in completing production work -- is delivered.

The automobile assembly plants in which I worked and directly observed others working were rich with flows of material, information, and services. In all of Toyota's, those who needed something made their request directly to a pre-specified supplier with a 'binary' request-signal that could be interpreted as 'send' or 'don't send' the specified product, service, or information in the pre-agreed form and quantity. Each link in these internal supply chains contained built-in-tests that the connections were working as designed. In no non-Toyota plant did I observe a similar approach to specifying pathway and connection designs and operating them with built-in-tests that immediately signaled that the pathway or connection was not operating as expected.

Figure 3 shows essential information elements of the assembly line work areas that I observed at Toyota's NUMMI, Georgetown, Kyushu, Takaoka, and Tsutsumi assembly plants. In the diagram, several team members are working. For instance, installing the front, passenger seat -- a job I did at a non-Toyota plant and which I observed at each Toyota plant that I visited -- involves moving the seat from a conveyor into the car body using a hoist and affixing the seat to the car body with four bolts, each of which is tightened with a torque wrench. At Toyota's Georgetown plant, this work was sub-divided into seven discreet elements meant to take a total of 51 seconds.[2] Painted haskmark lines on the floor subdivided the work station into ten pieces. Since one cycle of work was meant to occupy 51 seconds and was meant to be completed within the single work zone, each subdivision was worth 5.1 seconds of work. This provided a first level diagnostic for work. For example, if a worker had completed the first three seat-installation steps, meant to take 15 seconds according to the activity's design, but the car had traveled past the fourth hash-mark (i.e., 20.4 seconds had elapsed), then the worker had fallen behind and needed help in completing his or her work from the team leader. The team-leader, noting the

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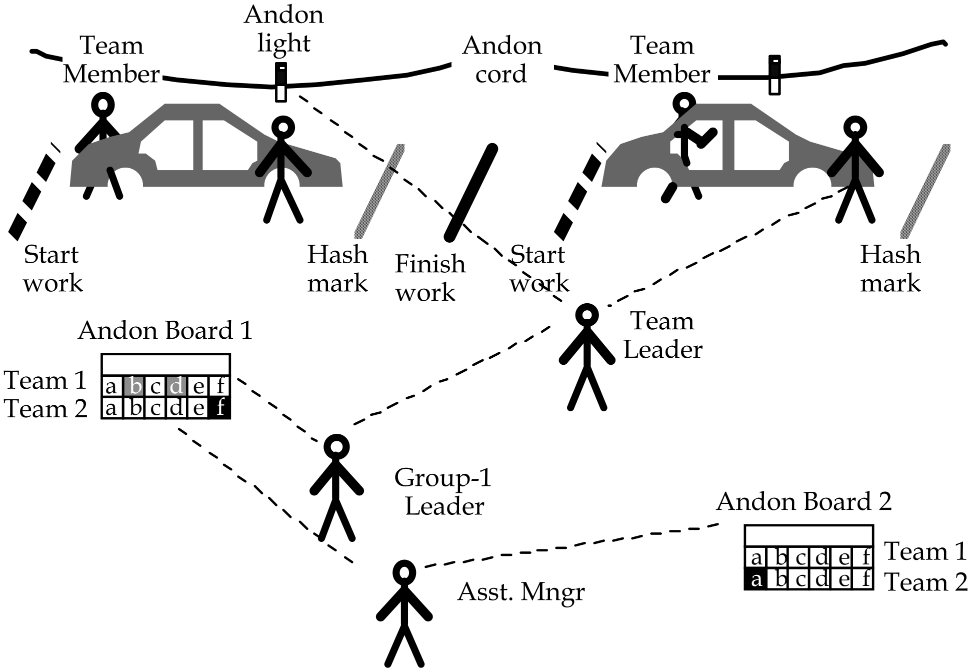
[2] Source: Observation of the team member, conversation with the team member and team leader, and standardized work chart.

disparity between the expected progress of the 'standardized work' and the actual progress, came to assist the line worker. Thus, an agreed pre-specification of how work was expected to proceed allowed for a built-in, real-time diagnostic that this piece of the system was operating incorrectly and resources could be brought to bear for immediate remediation close in time, place, and person to the problem's occurrence.

Figure 3: Information rich shop floor: Binary signals to deliver assistance



Conversely, if the worker had completed the first four steps by the fourth hash-mark (20.4 seconds into the cycle) though they were expected to take 29 seconds, then this too would signal a problem. The worker might have skipped a step and so was further along than expected in the activity's design. Alternatively, the activity-design might have assumed more time was needed than was actually necessary, creating the opportunity for a micro-rebalancing of work-elements within the team, contributing to higher overall efficiency. In either case, the built-in test compared the worker's actual progress to his or her expected progress, and it automatically sent a signal to the team leader to investigate why there was a disparity between what was expected according to the activity's design and what was actually transpiring. This created the opportunity to find and address problems close in time, place, and person to their occurrence.

The specification of a supply chain/pathway for assistance, specification of how to signal for help, and built-in tests that requests for assistance were being met with adequate responses extended through several hierarchical levels.

At the Toyota plants in which I gathered data, a team member pulled an andon-cord when he or she recognized that help was needed. This did not stop the assembly line from running. Rather, it generated a signal that a particular person was having difficulty completing his or her work. This was indicated by a yellow light corresponding to that particular work station on an 'andon board' (the gray 'b' for Team 1 on Andon Board 1 in Figure 3). Were the team leader able to resolve the line-workers problem within the cycle time, he would switch the light off, and this would be interpreted as a successful response by a supplier to single customer request for help. Similarly, delivering the correct box of parts would be interpreted as a successful supplier response to a customer request made using a kanban card.

If the team leader could not resolve the line-worker's problem within the 51 second cycle time, then the light switched automatically from yellow to red (the black 'f' for Team 2 on Andon Board 1 in Figure 3). This was a signal to the group leader that a particular team leader needed help helping a line-worker.

Other signals, built into the system, allowed the team leader to make a 'request' for assistance to the group leader. For instance, were the team leader asked to assist two line workers at the same time, the team leader would have to disappoint one in order to meet the requirements of the other (i.e., Andon Board 1 shows both the 'b' and 'd' locations in yellow/gray for Team 1). This was a signal to the group leader that the team leader needed help to complete his or her own assistance work.

The practice of specifying pathways and connections and monitoring them with built-in tests continues in this example. The leader of Team 1 is requesting help from Group Leader 1. The leader of Team 2 is also requesting help as indicated by the red/black box on location 'f'. That the Group Leader is being asked to help two team leaders simultaneously is a problem because the needs of only one can be met at once. Hence, this combination of lights becomes an unambiguous, binary request signal from the Group Leader to the Assistant Manager to provide assistance. At Toyota's plants, I observed that the pathway for assistance was specified for each line-worker and extended through the hierarchical levels of team leader, group leader, assistant manager, area manager, and production manager. The mechanism by which assistance was requested (i.e., problem solving work was coordinated) was also specified, and the pathways and connections had built-in tests to signal immediately when they were not working properly.

5.2 OTHER SPECIFIED, SELF-TESTING, ACTIVITIES CONNECTED INTO PATHWAYS

The two examples provided above are drawn from many observations that cumulatively led me to conclude that Toyota designs work systems guided by Rules-in-Use. These are applied to pathway design -- the delegation of responsibility in terms of who will provide what to whom, connection design -- the mechanisms by which immediate customers and suppliers will communicate or transfer products, services, and information, and activity design -- the means by which individuals will convert inputs into outputs for use by someone else.

In the TPS managed organizations in which I gathered data, the expected functioning of [tending to] all activities, connections, and pathways be specified before they are used. Built-in-tests immediately diagnosed that the activity, connection, or pathway was actually working as expected in the specification. If not, then the activity, connection, or pathway was redesigned close in time, place, and person to the occurrence of a problem. These patterns of work-system management were not evident in the non-TPS organizations in which I gathered data. The sections that follow briefly summarize other field observations that contributed to the inductive recognition of patterns as Rules-in-Use that are the essence of the Toyota Production System.

5.2.1 PATHWAY SPECIFICATION AND SELF-DIAGNOSIS

The Toyota team of which I was part specified a pathway for each of a supplier plant's 300 parts. For instance, rather than having part 665 stamped on press 4 or 5 and welded on station 21, 22, or 23, we established that 665 would go to Press 4 and then to welding station 22.

This was a two-fold departure from the plant's previous approach. With specified pathways, requests for goods and services (i.e., production instructions) began downstream at the end customer (as in **Error! Reference source not found.**) and progressed upstream from shipping to specific welding stations to specific stamping presses, and to the raw material, steel-coil stores. This replaced the previous practice of a staff-person generating a daily production schedule for each machine that was then disseminated vertically from the production controller through the area foreman to the individual press and welding station operators.

There was a second resulting change in practice. The plant had been using a 'bank teller' approach for controlling material flow with jobs queuing for the next available server (i.e., stamping press, welding station, or shipping worker). With our scheme, parts traveled to a specific, designated server instead.

I gathered data at several Toyota suppliers including Toyoda Bushoku, Araco, Taiheiyo, NHK, and Aisin (two plants). At each, *every* part type had a specified pathway over which it was to take form. In none was workflow managed with the 'bank teller' approach of jobs queuing for the first available server with work instructions diffusing downward from a production controller.

Pathway specification was not limited to material flows. As illustrated earlier, assistance pathways also were specified, each line-worker having a specific team leader from whom to ask for help, each team leader having a specific group leader from whom to ask for help, etc. Again, this stands in sharp contrast to a 'pooling' approach that would have the first available helper respond when someone had a problem.

In short, the consistent behavior that I observed in TPS-managed organizations was to have products, services, and information flow over pathways (i.e., from activity-doer to activity-doer) that were specified in terms of who got what from whom. Products did not follow a pathway that was stochastically determined based on arrival rates, cycle times, and first-availability of next process-step servers.

5.2.2 CONNECTIONS

The detailed examples above illustrated the TPS Rules-in-Use approach to connecting immediate suppliers of products, services, and information with immediate customers. Connections were direct, with built-in-tests that signaled immediately when the supplier was not working in synchronization with his or her customer. The approach taken in those two examples was consistently evident in other TPS-managed organizations, but not elsewhere. Work-activities on the specified production pathways of the Toyota suppliers mentioned above were linked in an identical fashion, as were their internal supply chains for production help, equipment maintenance, and other services.

5.2.3 ACTIVITIES

In the TPS-managed organizations in which I gathered data, a consistent approach was evident in the design of assembly line work. At its Kentucky plant, mentioned earlier, installing a seat required a total of 51 seconds and was demarcated into 7 distinct steps, each with an expected sequence, location, completion time and expected outcome. Deviations from the design triggered signals that the line worker was in need of assistance. Exactly this same approach was taken with other assembly line jobs at Toyota's Kentucky plant, and seat installation and other work at other Toyota plants (NUMMI, Takaoka, Tsutsumi, Kyushu) also was specified with built-in, self-diagnostic tests. In contrast, I installed seats and did other assembly line work at a Toyota competitor, and the work was not precisely defined. Furthermore, there was less ability to signal immediately that a problem had occurred. At Toyota, a line-worker's problem immediately triggered a specific team leader to do his or her assistance work, and the team leader's problem in providing assistance immediately triggered a specific group leader to provide assistance. In contrast, at the non-Toyota plant in which I labored, problems were entered into computer consoles for later attention with no mechanism in place to call the first and second level supervisors for immediate help.

This emphasis on specifying activity designs with built-in tests was peculiar to and pervasive at the TPS-managed organizations in which I gathered data. During my membership on a Toyota team that was teaching TPS to a first-tier supplier, one of our objectives was to reduce the changeover time on the stamping presses in the plant. Our first step in this was to document how a die change was done. We then repeated that sequence of work-elements with the workers. As problems impeded the set-up specialists from replacing the tool used to stamp one part with the tool used to stamp the next, we immediately developed a 'counter-measure', a change in the work design, so that the activity could be done with greater efficiency and effectiveness. For instance, one of the workers recognized that the forklift operation had trouble centering the die on the bed of the press because the tool obstructed the driver's view. The worker's counter-measure was to develop a simple target for which the driver could aim. From one try to the next, this modification shaved 50 seconds from the changeover. On a subsequent trial, a worker realized that his associate was matching scrap chutes to each tool in a trial and error fashion. As a counter-measure, they color coded scrap-chutes of different widths with the location to which they were to be attached to the die. Having defined the die-change work with high-resolution, another person realized that considerable time was spent getting confirmation that the new die was making acceptable parts. The counter-measure for this problem was to place a jig by the side of the press so that confirmation of part-quality could be nearly immediate, at the work-site, rather than delayed, and away from where the work was being done. As a result of these many changes, each implemented in response to individual problems, part production on this press went from 15,080 in first week of April to 23,140 in the final week of the month. Changeover time dropped from several hours to 18 minutes, on average. Cumulative overtime for the press, which had been 30 hours in the first week of April, was eliminated, and lot sizes were driven down from 3 weeks of demand to 4.7 days.

In short, the Toyota approach was to specify the work associated with this machine. The purpose of the specification was not to entrench ‘best practice’, per se. Rather, it was to use the current best practice as the basis for discovering large and small problems. These, when remediated, contributed to substantial improvements on multiple performance measures. Solving these individual problems, one-by-one, was the means by which I was learning TPS and we were teaching it to the supplier’s workforce.

The approach we took of specifying the die-change work with built-in tests matched the approach at other TPS managed facilities. At one, hoists that carried heavy tools throughout the shop were retrofitted with focused light beams that an operator could center on a target before lowering the load. Previously, without the built-in test that the hoist was properly located, the operator would lower the load to the ground, roughly estimate how much adjustment was needed, raise the load (in the z-direction) move it in the x-y plane, and relower it. This of course consumed far more operator and equipment time and exposed the load to damage from the repeated lifting and lowering.

That work was specified in design with built-in tests in operation extended to activities done with less frequency. I visited an Araco plant twice, in 1996 and 1998. In 1998, I learned that equipment that had been three separate work cells in 1996 had been consolidated into a single work-site. The equipment was specialized to particular families of parts, demand for which had diminished due to model changes. The three cells were consolidated into one so that the equipment would occupy less space and could be operated by one person not three. Though this consolidation was a one-time event, it was nevertheless scripted as 13 elements. However, the supplier did not blindly adhere to the script. Rather, performing the first element revealed problems in its design that led to revision of the second step. Experience with the second step led to redesign of the third and so on until completion. Adler, Goldofstas, and Levine (1997) make a longitudinal comparison of two new model introductions process at NUMMI through interviews, plant visits, and document reviews. Their work also reveals this consistent pattern of specification of work-design, built-in-tests to diagnose the work as it is being performed, and improvement of design in response to individual problems for a range of processes including standardized assembly work, team and group leader work, production system design, and the process by which the production system design was completed.

6 DISCUSSION

6.1 RECAP: TOYOTA PRODUCTION SYSTEM RULES-IN-USE

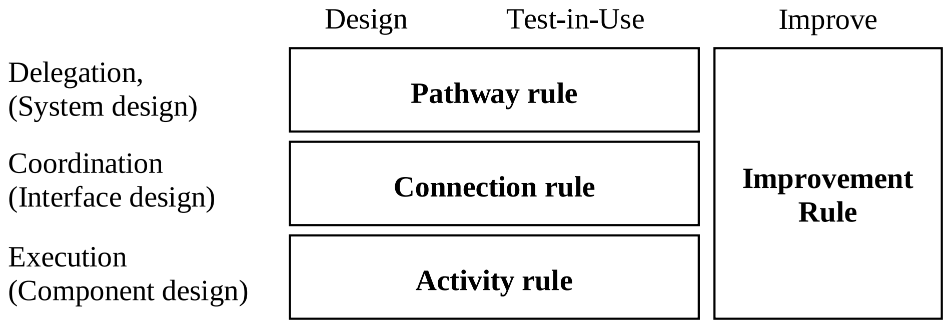
I concluded that these behaviors which I've termed Rules-in-Use are the essence of Toyota's management system because:

- *At organizations in which people have learned from expert Toyota teachers*, the Rules [as reflected in of actual behavior] were evident across functional specialties, hierarchical levels and across a products, processes, and markets, and the Rules explain my field observations with fidelity.

- *At organizations that have not learned from expert Toyota teachers*, similar patterns of behavior were evident only to a limited extent, regardless of function, product, process, or market. *Systematic* behavior that was similar to that underpinning the TPS Rules-in-Use was not evident.

Common to the Rules are specifying-every-design, diagnosing-every-use-with-built-in-tests, and improving with every problem close in time, place and person to its occurrence. Thus, the common themes of the Rules are that expectations of how something will work should be articulated in advance and gaps between the expected and the actual performance should be recognized immediately. This approach treats individual work and systems of work as experiments that prompt improvement efforts that both better processes and also build knowledge. The role of each rule is indicated in Figure 4.

Figure 4: Role of each Rule-in-Use



The pathway rule states: Specify who will get what product, service, or information from whom over a simple[3] pathway. This creates a refutable hypothesis that can be tested by asking, 'Was the actual supplier the expected supplier?' If the customer's need was met by an *unexpected* supplier, then the pathway was under designed; too few resources were committed. Conversely, if an *expected* supplier was not needed, then too many resources were committed to the pathway.

The connection rule states: Specify how each customer will make 'binary' requests that indicate what to deliver, when, and in what volume directly of an immediate supplier, and specify how each supplier will make responses directly to his or her immediate customers. This creates a refutable hypothesis that can be tested by asking, 'Was the actual response equal to the expected response?' If the supplier fell behind and orders accumulated, then customer need was underestimated or the supplier capability was overestimated. Conversely, if the supplier produced and delivered ahead of actual customer need, then the customer need was overestimated or the supplier capability was underestimated.

The activity rule states: Specify each activity's work-element content, sequence, timing, location, and outcome. This creates a refutable hypothesis that can be tested by asking, 'Was the actual activity performed as designed, generating the expected outcome?' If the work was not performed as designed, then something about the worker's preparation caused him or her to fail. If the work was done as designed, but an inadequate outcome resulted, then the design itself was inadequate.

The improvement rule states: Specify that the smallest group affected by a problem (i.e., the activity doer or the connection or pathway users) is responsible for its immediate resolution. Specify a qualified teacher to help in problem solving work. Solve problems by constructing bona fide, hypothesis testing experiments. If problems cannot be resolved by the affected individual or group, then readjust the scope and scale of hierarchical responsibility to match

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[3] No loops or intertwined branches.

better the actual nature and frequency with which problems are actually occurring. Continue to improve in the direction of IDEAL production and delivery. [4]

This rule converts improvement work into refutable hypotheses that can be tested by asking, 'Are problems being recognized and 'counter-measured' when and where they occur by the people affected by the problem?' If problems are not solved in this way then individuals can be trained and groups can be re-formed based on updated expectations of the nature and frequency of problems.

6.2 SIGNIFICANCE

Pathways, connections, and activities of organizations that produce much the same goods or services may be designed and operated in considerably different ways according to Skinner (1974) Clark, Hayes, and Wheelwright (1988), Womack, et al (1990), and others. The delegation of responsibility for smaller parts of a larger whole may vary considerably in scale, scope, and complexity, and pathways over which materials, services, and information flow may range from highly intertwined to simple and focused. Coordinative mechanisms can differ too. Individuals may be connected to the larger whole by centrally generated schedules and delivery of intermediate goods to centralized stores. Alternatively, people may learn when to make how much of what and may deliver based on those instructions through connections that link them directly to their immediate customers. The same work -- installing a part, changing a stamping die to create the part, maintaining the stamping machine, training someone to maintain the machine, etc. may differ by work-element content, sequence, timing, location, or outcome.

The new product development literature recognizes that differences in product quality, cost, and feature selection can be explained by differences in product-system architectures, interfaces linking sub-systems, and individual components [Clark, (1985), Henderson and Clark, (1990), Baldwin and Clark (2000)]. Similarly, this paper's framework allows us to link differences in organizational performance to differences in specific organizational features of (a) architecture: responsibility delegation as reflected in pathway design (who does what for whom), (b)

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[4] IDEAL production and delivery: defect-free, on-demand, one-by-one, immediate, no waste and safe physically, emotionally, and professionally.

interfaces: coordinating connections for communicating products, services, and information, and (c) components: individual work-activities.

Clark (1985) cites Abernathy and Utterback in stating that the design of complex technical systems progresses in a hierarchical fashion. First, there is a search for a dominant architecture, and then, once a dominant design has been established, interface standards are established as to how sub-systems are to be joined, and finally sub-system and component technologies evolve to enhance performance. Clark adds the important insight that the search at the architectural, interface, and component level occurs through problem solving that closes gaps between product capability and market needs, that there is contingent aspect to achieving a good design. Ward, et al (1996) explains Toyota's advantage in product design (designs that are more manufacturable created with less lead-time and fewer engineering hours) in terms of an iterative, convergent 'set-based' search for the correct architecture, interface, and component designs that is made possible through frequent, rapid-feedback, low cost experiments. For example, Ward et al find that Toyota conducts many more scale-model prototype tests, with later commitment to critical dimensions than its best design competitors yet still manages to outperform in the design process equivalents of quality, lead-time, and cost.

In the organizational design domain, Lawrence and Lorsch maintain that the appropriateness of an organization's structure is contingent on the nature and the rate of change of the problems it must address. Nelson and Winter offer that an organization develops 'routines' for addressing the problems confronted by its members as they engage in collaborative work.

This paper proposes that the root-cause of Toyota's competitive advantage is that it has developed a set of management principles, its own meta-routines or dynamic capabilities, that allow it to engage in frequent, low-cost, rapid feedback experimentation in the organizational equivalents of architecture, interfaces, and components, these being pathways, connections, and activities. Not only does the built-in-testing aspect of the Rules-in-Use convert every work and work-system design into a bona fide experiment, it does so in a way that recognizes that information is 'sticky' and highly specific to time, place, and person [von Hippel (1994)].

This paper concludes with the proposition that establishing designs that are deliberate experiments is critical when work must be done in coordinated collaboration. If individual learning to acquire a task-skill occurs through frequent practice that allows for repeated failure (or shortfalls) as intermediate steps to acquiring mastery of a subject or skill, then group learning on delegating responsibility and coordinating efforts must also be done through repeated practice that allows for repeated failures or shortfalls. However, if people conduct delegation and coordination experiments in isolation, then their own attempts to learn will create noise for those with whom they are connected. With specification and built-in-testing, collaborative experimentation in coordination and delegation mechanisms is more feasible.

7 CONCLUSIONS

This paper began by citing Hayes and Pisano who urged managers from avoiding the pitfall of pursuing a 'one best way' approach to running operations. Rather, they encouraged the pursuit of strategic fit grounded in the development of capabilities that allow organizational adaptability in the face of internal disturbances, external changes, and emerging opportunities. This makes obvious sense. In the product domain for instance, designers would be considered daft if they encourage a single 'best design' for all computer users. Rather, the market has unveiled numerous designs whose architectural, interface, and component differences are driven by a different value proposition at the system level.

For many years, TPS and its derivatives such as lean manufacturing have been viewed as a one-best way approach for managing operations. There are inherent problems presented by a universal adoption of 'best practice', and the obvious practical problems are certainly illuminated when we extend the idea of 'one best way' from the design of complex work systems to the design of complex technical systems, as in the preceding paragraph. Nevertheless, the methods associated with Toyota had an impressive currency largely because of the long-standing recognition that Toyota is an outstanding manufacturer.

As a result, great attention has been paid, on one hand, to Toyota's 'Just-in-Time' production control tools and, on the other hand, to its ability to improve continuously on the other. This paper argues that the practices are tightly integrated. Toyota designs work systems so that they generate information immediately that a problem has occurred. These signals become the impetuous for the problem solving activities that allow TPS-managed organizations to engage in an adaptive, hierarchical search for superior designs for an organization's system 'value proposition', architecture, interfaces, and component activities. Thus, TPS, as embodied in Rules-in-Use, is not a one-best-way, per se, in terms of the final organizational form it discovers, but it is certainly a superior way for facilitating situated, problem-solving based learning that leads to organizational forms that fit strategically with the organizational mission.

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9 ACKNOWLEDGEMENTS

This work would have been impossible without the substantial support provided by the Harvard Business School Division of Research and the access, direction, and instruction provided by members of the Toyota Supplier Support Center (‘TSSC’), Toyota Motor Corporation employees, and people at many Toyota suppliers. At Harvard, I am particularly indebted to H. Kent Bowen and at Toyota to Hajime Ohba, general manager of TSSC. Both have been exceptional teachers.