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The Essence of Just-in-Time: Imbedding diagnostic tests in work-systems to achieve operational excellence

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ABSTRACT

This paper asserts that problem identification and problem solving processes can be integrated into work processes by imbedding tests that evaluate system-performance with every exchange of products, services, and information. These tests make it unambiguous when, where, and by whom problem solving is necessary. As an integral part of the production process, this low-cost, on-going application improves processes and deepens a firm's process knowledge.

These assertions are based on an ethnographic study of how some firms sustain outstanding performance through iterative problem solving. How firms may sustain a high level of operational performance is a fundamental concern of organizational theory and operations management. Field research on this topic revealed attributes of just-in-time ('JIT') as practiced by Toyota and its affiliates -- companies identified with JIT principles and that have been recognized for outstanding performance -- that had not been fully explored. Whereas JIT's role in controlling material flows through sequential processes has been much discussed, Toyota and its affiliates also use JIT to evaluate work-system performance with high frequency and resolution. When work is not proceeding as designed, problem solving begins close in time, place, and person to each problem. These results suggest using JIT to advance process knowledge from lower to higher stages rather than applying JIT just to processes that are already well understood.

KEYWORDS

Toyota Production System, Just-in-time, process improvement, problem solving, mass customization

1 INTRODUCTION

Academics and practitioners have given just-in-time ('JIT') considerable attention as a means of controlling material flows through linear processes.[1] This attention reflects an on-going interest in finding ways to optimize inventories and throughput times [Boccard (1990), Deleersynder, Hodgson, Muller, and O'Grady (1989), Lee (1989), Sarker, (1989), Hopp and Spearman (2000)]. Less attention and research, however, has been paid to JIT as a way to facilitate problem solving, process improvement, and learning as precursors to outstanding performance.

This is a missed opportunity. Organizational theory and operations management have been especially interested in how organizations *achieve superior process designs* [Lawrence and Lorsch (1967), Skinner (1974)], *iteratively* [Nelson and Winter (1982)], *through problem solving* [Clark, Hayes, and Wheelwright (1988), Leonard-Barton (1992), Jaikumar and Bohn (1992), MacDuffie (1997)]. Yet, problem-identification and problem solving attributes -- essential to JIT -- and their consequent impact on process improvement -- have been addressed far less.

This paper focuses on how JIT integrates the 'routine' work of producing and delivering products, services, and information with problem identification and process improvement. Thus, this paper extends previous research by building a theory of how imbedding self-diagnostic tests in work can convert static processes into frequent, structured experiments that build process knowledge and foster continuous improvement.

This paper is organized as follows. Section 2 explains why Toyota and its affiliates were chosen as research sites. Section 3 describes my ethnographic research methods. Section 4 presents a nested case study of a factory that illustrates how imbedded tests converted production and delivery work into structured experiments. Section 5 generalizes management principles from the case study, and Section 6 shows how these principles are applied in a different context, to a logistics system. Section 7 discusses the implications of these results on practice and theory.

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[1] Research interest in JIT was evident from an ABI Informs keyword search. It found 1,428 articles for 'just-in-time' from 1983 to 1997, 255 for 'kanban', and 72 for 'pull system'.

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)].

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.[2] 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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[2] 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 Case study #1: Aisin -- managing high volume, mass customized production[3]

Just-in-time has been discussed as a way to control flows of material through sequential processes, with particular emphasis on the pacing by downstream processes of the production and delivery work done by upstream processes. While this and associated issues of inventory control are important aspects of JIT as used in practice, this emphasis misses attributes of JIT that contribute to problem solving, process improvement, and the operations-based sustainable competitive advantage often associated with Toyota and its affiliates.

Several variables are critical to properly applying these attributes. They include *specifying* how work is expected to occur before performing it, *imbedding tests* in work-designs to signal immediately when work is not occurring as expected, and responding quickly to signals with *problem-solving-processes*. Problem solving not only should be restorative in the short term but corrective in the long term. The combination of specification with imbedded tests converts work-designs from static processes into frequent, structured experiments that test the assumptions built into that work. Problem solving done close in time, place, and person to problem occurrences capitalizes on the ability of the imbedded tests to indicate when assumptions in the work-design are incorrect. Therefore, this application of JIT simultaneously builds process knowledge and capability.

While based on data from automobile industry plants, the approach outlined in this paper was evident in Toyota Production System managed organizations, more generally. Aisin, for instance, a first-tier, auto-parts supplier to Toyota, also manufactures consumer products such as sewing machines and computerized bathroom scales. People from the Toyota staff recommended Aisin's Seiki factory, which produces mattresses, as a research site because of its adroit application of TPS. The plant transitioned from mass production to mass customization,

[3] I gathered data at this plant for one day in 1996, two in 1997, and one in 1998, with follow-up correspondence and phone interviews. I shadowed workers and followed products with Toyota people. I interviewed managers about a major process redesign and workers about a quality circle. I also reviewed documentation of process and performance changes and visited retails stores to understand customer interfaces. This paper's data are from a larger set available from the author or in printed form from ProQuest, http://tls.il.proquest.com/hp/Products/DisExpress.html.

with continued increases in volume, variety, and productivity and with simultaneous reductions in lead-time and inventory (table 1). This transition was achieved despite challenges characteristic of making complex items more generally, such as multiple process stages, imbalanced and variable process times, product variety, and fluctuations in the mix, volume, and timing of demand. Thus, rather than facing static trade-offs along a fixed ‘production possibilities frontier’, the plant repeatedly improved its manufacturing process and continued to achieve much better frontiers.

Table 1: Aisin mattress production: historical mix, volume, and inventory

	1986	**1988**	**1992**	**1996**	**1997**
Styles	200	325	670	750	850
Units per day	160	230	360	530	550
Units per person	8	11	13	20	26
Finished goods (days)	30	2. 5	1.8	1.5	1.5
Productivity Index	100	138	175	197	208

4.1 BASIC PRODUCTION STEPS

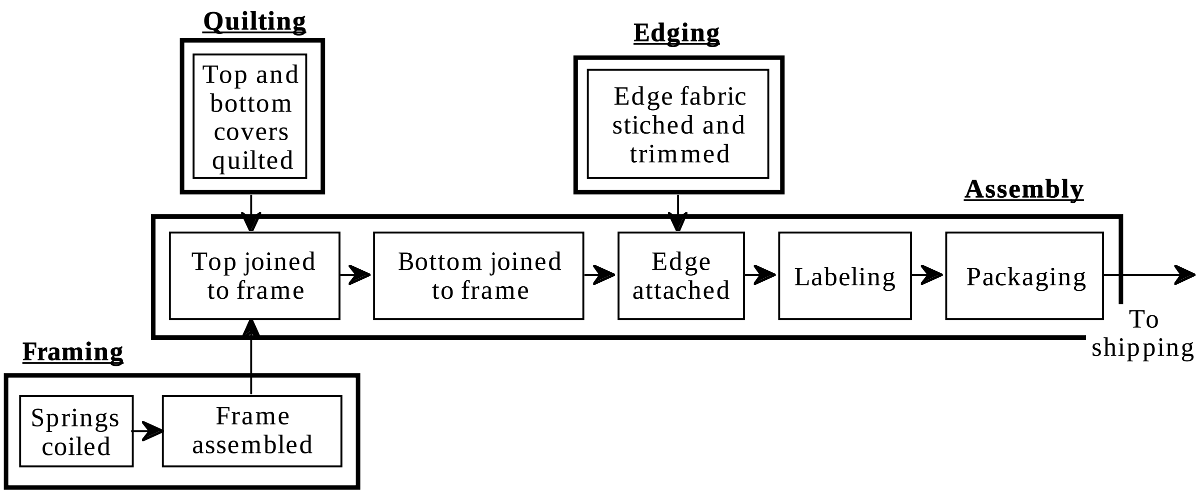
In 1997, Aisin’s Seiki plant produced 550 mattresses per day for both individual and institutional consumers. Customers in furniture stores could test model beds and examine fabric samples, quilting patterns, and other materials. From a combination of 850 alternatives, they could specify size (small, medium, or large), cover fabric, lining material, quilting-pattern, trim color, and firmness. Retail customers received home delivery from the plant within three days. Institutions also could specify mattress design but accepted delivery delays.[4]

Aisin created mattresses in distinct steps (figure 1). In ‘framing’, springs were coiled and joined into a frame. In ‘quilting’, liner layers were sewn to cover layers. In ‘edging’, the bolt of

[4] Aisin was moving towards individual orders triggering production and delivery in the sequence that each was received, but the production sequence did not yet match the order sequence exactly. Although the plant operated a fixed time each day, retail orders peaked on weekends, and some customers wanted delivery postponed. Therefore, within a week, institutional orders were added or delayed to level production, and 1.5 days of finished goods were kept on hand to accommodate shipping schedules. Within production shifts, there was some batching at quilting by fabric, size, and thread because of changeover times.

material for the circumference of the mattress was stitched. Prior to labeling, packaging, and shipping, these three 'sub-assemblies' were crafted into complete mattresses.

Figure 1: Simplified process flow for mattress production

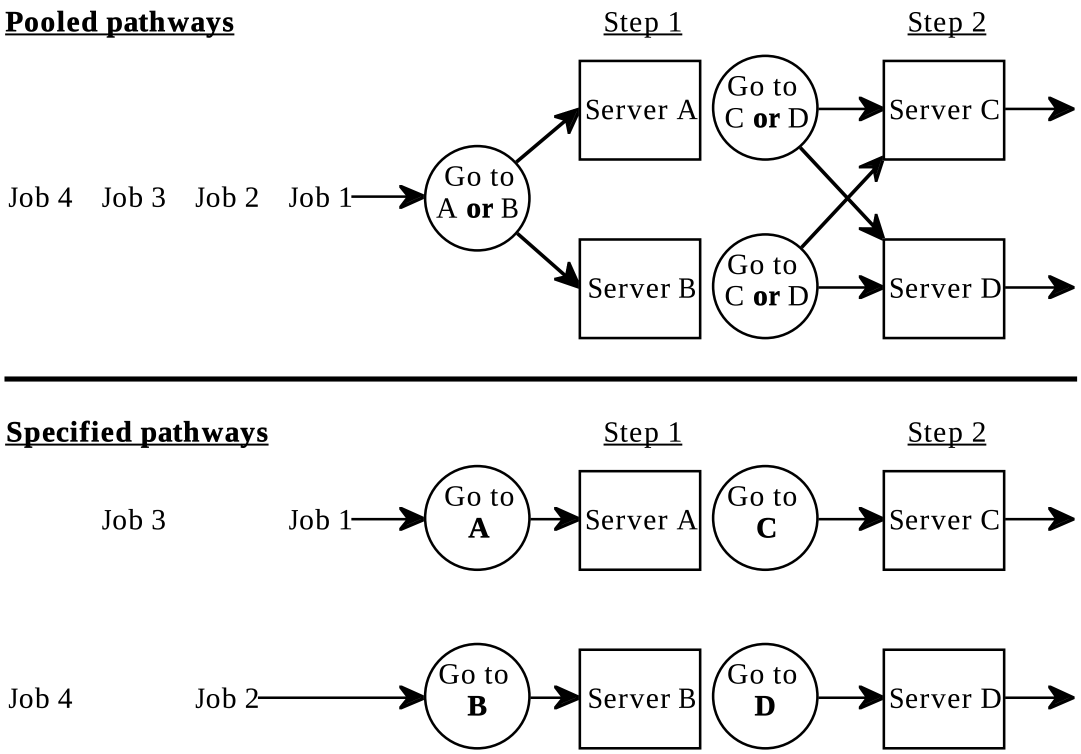


4.2 SPECIFIED PATHWAYS FOR MATERIAL AND INFORMATION FLOWS

4.2.1 MATERIAL FLOWS: DIRECT FROM SPECIFIED SUPPLIERS TO SPECIFIED CUSTOMERS

Each mattress followed a *specified* (predetermined) production pathway, even though equipment at several stages was interchangeable. Furthermore, material traveled *directly* from those who had just worked on it, whom we will denote as 'suppliers', to those who would next use it in their own work, whom we will denote as 'customers', without first going through a centralized store. For instance, neither the framing lines nor the assembly lines specialized in small, medium, and large mattresses only, and framing was disconnected from assembly by small, first-in, first-out stores. Yet, material did not go *from any* framing station (the supplier) *to any* assembly line (the customer) -- a pooled approach. Rather, flows were specified, so jobs went to people or machines within process-stages in a scripted sequence. This general distinction between pooled and specified pathways is illustrated in figure 2.

Figure 2: Pooled versus specified flows

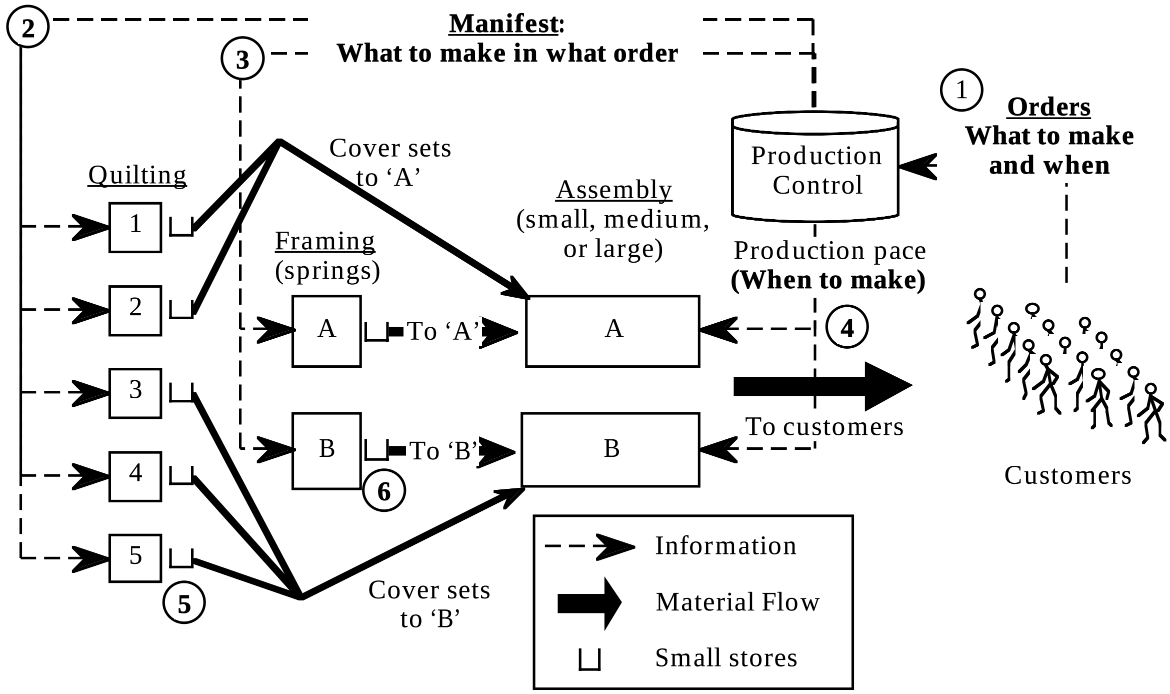


For example, framing line ‘A’ always sent its frames, regardless of size or firmness, to assembly line ‘A’, and framing line ‘B’ always sent its output to assembly line ‘B’, also independent of size or firmness. Similarly, each of the five quilting lines made cover-sets of any size, with any material, in any stitching pattern throughout a day. Yet, at any given time, each quilting line was dedicated to feeding a single assembly line only, as in figure 3.

4.2.2 PATHWAYS FOR INFORMATION: OVERLAID ON PATHWAYS FOR MATERIAL

Pace setting information traveled directly between immediate customers and immediate suppliers over the same specified pathways as products and services. This allowed those who used a product or service, the ‘customers’, to control the production and delivery pace of the people who provided particular items, the ‘suppliers’. This was true in process-stages, between adjacent process-stages within the plant, as in figure 3, and between the plant and its external customers on one hand and its external suppliers on the other, as in figure 4.

Figure 3: Aisin material and information flow: circa 1997



Note: edging not included in diagram for simplification

4.3 DIRECT, UNAMBIGUOUS PACING OF IMMEDIATE SUPPLIERS BY IMMEDIATE CUSTOMERS

In Aisin's TPS system, pathway specification for products and information was a prerequisite for imbedding tests. The other prerequisite was structuring information so that each customer request was *unambiguous* and could be compared immediately with each supplier-response to ensure that the system was operating as expected. Requests establishing production mix, volume, sequence, and timing, were *unambiguous* in that:

(a) there was one way only to request each product or service,

(b) there was one request for every unit,

(c) requests went to a specific supplier, and

(d) each request established fully the criteria for a good response.

4.3.1 ESTABLISHING PRODUCTION MIX, VOLUME, AND SEQUENCE

Information was *unambiguously* structured between external customers and the plant, within the assembly line, between assembly and its feeder process-stages, and between the feeder processes and their external suppliers. For example, customer orders from furniture stores (item 1 in figure 3) determined production mix, volume, and delivery timing for the plant as a whole. Based on these orders, production control created printed manifests (a) as the only way of establishing the production mix, volume, and sequence and (b) with one manifest for every mattress. Production control sent an individual manifest for each mattress to the start of the quilting line (item 2) and one that corresponded to the same mattress to the start of the framing line (item 3). Since manifests went to both quilting and framing in the same sequence, both process-stages could make sub-assemblies for the same final product in the same order. Manifests traveled with mattresses as they took form, so that at each step, (c) specific parts of each manifest told specific workers precisely what to do, and (d) information on each manifest established fully the criteria of what each worker had to do to achieve a good outcome.

4.3.2 ESTABLISHING PRODUCTION RATE

The plant also had (a) one way only to establish the production rhythm for the entire plant. (b) For every mattress for which a manifest-set was sent to the *start* of quilting and framing, a separate signal was sent to the *end* of the assembly line (item 4), indicating that (only the) next mattress was to be taken to shipping. This signal continued through the system (c), and established for each worker when to produce and deliver one more unit, and thereby (d) determined each person's correct production pace -- again, a good outcome.

4.3.3 CONTROLLING IMMEDIATE SUPPLIERS IN ASSEMBLY

Linking individual, customer orders to the end of production initiated a pull that extended upstream to external suppliers. For instance, each step in final assembly was designed so that work could not advance until it was both completed by the 'supplier' step and needed by the 'customer' step. Thus, shipping each finished mattress triggered the immediate upstream step of packaging, which then triggered the next upstream step, labeling, to send one unit forward. In this way, each person's work in assembly generated a signal that set the rhythm at which his or her immediate supplier could advance material and do work.

4.3.4 CONTROLLING SUPPLIER PROCESS-STAGES

First-in, first-out stores, which separated process-stages in the plant, were located between quilting and assembly (item 5) and framing and assembly (item 6). These stores, which served as transfer points for material and information,[5] were the only way to transfer units between the feeder and the assembly lines. They operated on a first-in, first-out basis. Therefore, the stores protected the unambiguous production mix and sequence established at the start of quilting and framing. In addition, an important operating rule specified that an upstream 'supplier' process-stage could not produce and advance another unit until its downstream 'customer' had pulled a unit from the store, thereby opening room for the next item in the production sequence. Consequently, stores also protected the production rate across process-stages. Because the stores held up to a fixed number of units, they accommodated some process speed fluctuation, and, as is explained below, had a system-diagnostic role too.

4.3.5 CONTROLLING EXTERNAL SUPPLIERS

Finally, quilting and framing had small stores for materials (i.e., quilting fabric and spring wire). As these were depleted, individual 'kanban' cards were sent to the person who ordered material, thereby automatically authorizing delivery of small batches of replacement supplies.

Each kanban card had an *unambiguous* meaning, as did the manifest and rate information described earlier. Kanban cards (a) were the only way of reordering certain materials and (b) were used every time a specific customer had to reorder material of a particular type. They (c) went to a specific supplier (i.e., the materials reorder person) and (d) established the criteria of a good response (i.e., the card for fabric-1 was different than that for fabric-2, and indicated a pre-agreed quantity, such as 20 meters worth of cloth).

The person who received the individual kanban cards reordered materials by sending a shipment's worth of kanban cards to the external supplier, on an established schedule, as in figure 4. By extending the rate and sequence with which customer orders were filled from within the Aisin plant to external suppliers as well, the entire system was linked to the mass-customization effort.

Each batch of kanban cards also had an unambiguous meaning. First, a batch of cards (a) was the only way to specify the mix and volume of the next shipment, and (b) was sent for every

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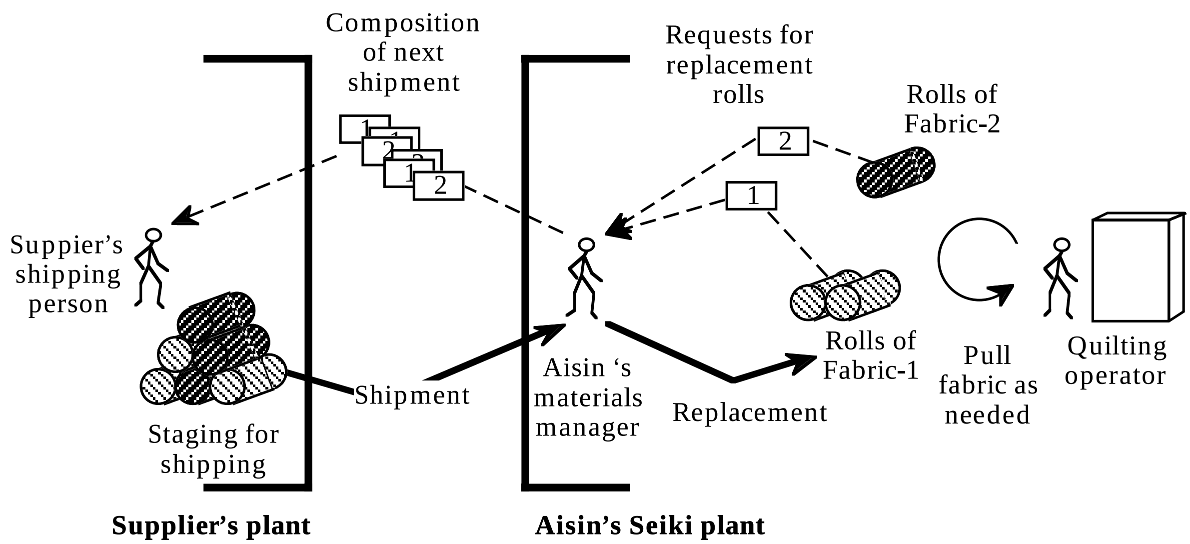
[5] For simplicity, figure 3 omits edging, but it too was controlled by mechanisms similar to those linking quilting and framing to assembly.

order. (c) Each shipment's worth of cards was meant for a particular person (i.e., the shipping clerk at the supplier plant), and (d) information on kanban cards specified the mix and volume necessary for a complete shipment.

Figure 4: Connecting quilting to material ordering and material ordering to the material supplier



4.4 UNAMBIGUOUS PROBLEM-SOLVING TRIGGERS BUILT INTO CONNECTIONS

Throughout the plant, a variety of *unambiguous* mechanisms ensured that work continued in concert. Within assembly, as described above, downstream activities rate-limited those upstream. Stores that linked adjacent process-stages facilitated flows upstream of information that triggered production and delivery and also flows downstream of material in response to those triggers. Kanban card systems linked Aisin's factory with its external suppliers.

Mechanisms were built into each 'connection' between adjacent customers and suppliers that signaled immediately that a problem had occurred that had caused a process to become unbalanced. These signals were also *unambiguous*, as shown below. [6]

[6] The data suggest that signals for ordering 'routine' products and services had the 'exclusive of all other means' aspect, whereas individual and group work might have multiple, imbedded diagnostics to call for assistance.

(a) A signal was triggered *every time* a problem condition occurred.
(b) The signal had a unique meaning in terms of *who was supposed to respond* to the signal.
(c) The signal had a unique meaning in terms of *what he or she was supposed to do* when the signal was received.

4.4.1 TESTING THE QUILTING-ASSEMBLY CONNECTION

For example, a small slide-rack near each quilting machine held up to five small wood disks. Each quilting operator attached a disk to each completed cover-set. When assembly took the cover-set, the disk was returned to its rack. Only if there was at least one disk in the rack could the quilting operator make the next set of covers.

This device did more than allow assembly to control the rate at which quilting did its work. It was also a system-diagnostic that triggered immediate problem solving. Each rack had built-in limit switches. A light flashed (a) every time a rack became empty of disks, telling (b) the specific team leader that quilting was ahead of assembly. (c) The team leader was to investigate immediately to see if and why there was a line imbalance, process incapability, etc. Then the team leader's job had two distinct but related components, (i) to begin short-term restorative actions and (ii) to initiate longer-term corrections.

Similarly, a light flashed (a) every time a rack became filled with five disks, telling (b) the specific team leader that quilting was behind assembly. (c) The team leader's job then was to investigate immediately why the system was out of balance both (i) to begin short-term restorative actions and (ii) to initiate longer-term corrections.

4.4.2 LINKING ASSEMBLY TO PROBLEM-SOLVING HELP

An imbedded diagnostic mechanism also allowed the final assembly line to pull problem-solving help from a specific supplier, in this case a team leader. A simple display indicated the number of mattresses each line was ahead or behind for the shift. This was not for communicating status to those doing production. Rather, the display allowed assembly to tell its team leader if it had encountered trouble meeting its target production rate. At 1, 2, or 3 units under target, the team leader did not intervene. However, (a) every time the display read '–4', (b) the specific team leader initiated (c) a series of corrective actions. The short-term corrective action was to add one person to the line who remained in place until the display read '+1'. To take longer-term corrective action, the team leader observed each person working while the line was recovering. Then he made inquiries to understand what caused the line to produce at an actual pace less than the pace at which it was expected to operate. This was the basis for process improvement.

4.4.3 DIAGNOSTICS TO KEEP PROCESSES RUNNING

As just described, the assembly line could operate up to three mattresses behind the target rate or be ahead by one. Rates below or above this range were always recognized as problems requiring intervention by a team leader. Similarly, Aisin imbedded inventory in connections for system stability, a practice contrary to some views of JIT and TPS as being doctrinaire in opposition to inventory. For example, the store between quilting and assembly was designed to accommodate fluctuations from one quilt to four quilts ready for assembly. Below or above this range, however, the team leader had to investigate what had gone wrong. Thus, imbedded tests made these connections 'attention focusing mechanisms' similar to 'E-lots'. E-lots, inserted to accommodate some process fluctuation, signal that a process has gone out of control when fluctuations are below or above pre-set limits [Jaikumar and Bohn (1992)].

Just as installing inventory to accommodate moderate process fluctuations may be contrary to popular understanding of JIT, so too is the means by which Aisin used system-diagnostics. These imbedded tests and the 'requests' for help that they generated were not meant to stop processes. Rather, they prompted an investigation as a first step in improving processes and thereby keep systems running smoothly.

5 COMMON FEATURES OF CUSTOMER-SUPPLIER CONNECTIONS

Aisin employed a variety of mechanisms to connect immediate customers with their immediate suppliers through flows of products, services, and information. All connections were *specified*, with *imbedded tests* that triggered *immediate problem solving*.[7]

5.1 SPECIFICATION

5.1.1 SPECIFIED PATHWAYS FOR MATERIAL AND INFORMATION FLOWS

Who would receive *what product or service* from *whom* was uniquely specified. This was true within assembly, between assembly and quilting and framing, between quilting and framing and their external suppliers, and between front-line production workers and team leaders who provided problem-solving assistance. For example, each mattress advanced over pathways specified from where to where rather than over pathways determined by a logic of pooling. Information that triggered production and delivery traveled upstream over the same specified pathways. When problems did occur, help came from a particular team leader, not from anyone who happened to notice the alert. By specifying flows of products, services, and information, it was then possible to specify how to operate the connections along the pathways.

5.1.2 SPECIFIED MEANS OF MAKING REQUESTS AND NATURE OF 'GOOD' RESPONSE

How to request a product (i.e., the next mattress or frame, quilting material, etc.) or a service (i.e., problem-solving help) was uniquely specified as well. Material requests were unambiguous in that the same mechanism (a) was the sole means for requesting a particular product, (b) was used for every unit, (c) went to a specific supplier, and (d) established criteria for an acceptable outcome. For example, completing one mattress signaled the immediate supplier to deliver the next. Creating a space in a store told framing to deliver one more frame, and returning a wooden

[7] Aisin 'connections' fell into two general categories, both of which were specified, with imbedded tests that triggered problem solving. (A) Some requests carried mix, sequence, *and* rate information, such as kanban cards or display boards for workers to call for help. These were used when variety was low and lead times were short. (B) Other requests were split into two pieces with one, i.e., the manifest, carrying mix and sequence information to the process start, and the other carrying the production rhythm to the end. These were for products with great variety and long lead times. Whether of the 'A' or 'B' type, connections maintained the pull logic of customer requests being the sole trigger for suppliers to produce and deliver and contained imbedded tests to trigger problem solving and process improvement.

disk to quilting triggered the production and delivery of one more cover-set. Delivering a kanban card signaled the reorder person to acquire one more unit of a particular fabric type (or wire type for framing) in a specific quantity. Delivering a shipment's worth of kanban cards to the external supplier established the next delivery's mix and volume.

Requests for assistance were unambiguous too. For example, (a) depleting disks in the rack that connected assembly and quilting generated a signal (b) to a particular team leader (c) alerting him to 'deliver' one unit of help. A '–4' appearing on the display above assembly had a similar meaning.

5.2 IMBEDDING TESTS IN CUSTOMER-SUPPLIER CONNECTIONS

Pathway specification for products, services, and information allowed requests and responses to travel *directly* between immediate customers and suppliers without information being intermediated through production control or material traveling into and out of central stores. Mechanisms for making unambiguous requests allowed immediate customers to control directly the production and delivery rates of their immediate suppliers.

Furthermore, one-by-one comparisons of requests and responses were possible because requests and responses were direct and unambiguous, and because the system operated according to just-in-time or pull logic that allowed only one production and delivery response for each specific request. Thus, diagnostics imbedded within each connection could immediately indicate whether or not problem solving was necessary.

5.3 PROBLEM SOLVING TRIGGERED BY BUILT IN TESTS

Diagnostics built into connections triggered process analysis and improvement. For example, the team leader's responsibility in responding to the signal that quilting and assembly were out of balance was to find out why and make take short-term restorations and longer-term corrections. When assembly was not at the target production pace, the team leader was to find out why and then take corrective action.

6 CASE STUDY #2: MANAGING LONG-DISTANCE, LARGE VOLUME MATERIAL FLOWS

6.1 CONNECTION DESIGN PRINCIPLES EXTENDED TO LARGER SCALE SYSTEMS

Customer-supplier connections between individuals, between process-stages, and between plants for Aisin's mattress production were all designed around the principles of specification, built-in-testing, and immediate problem solving, just as detailed above. When confronted with a logistics challenge of managing a continental supplier network, Toyota applied the same principles as Aisin, but across more plants and more processes separated by greater distances.[8]

6.2 BACKGROUND: TOYOTA'S NORTH AMERICAN LOGISTICS CHALLENGE

The Ypsilanti, Michigan, 'cross-dock' facility addressed a logistics challenge peculiar to Toyota in North America. In Japan, Toyota's plants and those of many suppliers have been clustered near 'Toyota City'. Even suppliers located greater distances from a Toyota plant have been situated along a narrow delivery corridor. Thus, in Japan, suppliers made frequent, small batch deliveries, with orders shipped from individual suppliers typically arriving as often as once an hour. For large or frequently used parts, trucks hauled supplies directly between the supplier and the customer. For smaller or less frequently used parts, 'milk-run' trucks followed looped routes, made quick, frequent stops, and picked up small batches of parts at several suppliers before delivering orders to the Toyota plant.[9, 10]

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[8] This example has both expository and methodological purposes. For expository uses, it shows a consistency in applying design principles across applications. On the methodological side, one way to ensure inductive research validity is testing models that are being developed by predicting how a system will operate before observing it, and determining how well the predictions matched the actual behavior. Visiting this logistics facility was an opportunity for this. Beforehand, I predicated a system design using information that I had about the logistics problem that the facility was meant to address and the principles that I had already developed about how Toyota would manage the just-in-time flow of material and information. I found that the actual system matched well the predication. This was confirmed by comparing my description of the facility's operations with those of a separate, independent observer [Johnson, 1998]. Therefore, this was a successful deductive test of an inductively developed formulation.

[9] Source: Interviews and site visits at Toyota and supplier plants in Japan.

In North America, in contrast, Toyota has built a network of geographically dispersed plants (i.e., Northern and Southern California, Kentucky, Indiana, West Virginia, and Ontario), and its suppliers, too, were geographically dispersed (i.e., some close to Toyota's large plants but many near Detroit). Therefore, direct, point-to-point, daily order-shipments from each supplier to each customer were not feasible, nor were milk-run routings in many instances. Therefore, Toyota established the cross-dock facility as a transfer hub.[11]

6.3 MATERIAL AND INFORMATION FLOWS THROUGH A NETWORK HUB

Although operating on a scale and with problems different than those of the Aisin mattress plant, the customer-supplier network of which the cross-dock facility was the hub operated with the same approach. It specified product and information pathways and request and response mechanisms, imbedded tests to detect problems, and kept problem solving close in time, place, and person to the occurrence of problems.

At supplier plants, orders for replacement parts arrived one-to-four times per day, and one-to-four times per day, milk run trucks picked up complete orders. Thus, from the perspective of the supplier, the connection or interface with its Toyota customers was no different than that between Aisin and its external suppliers or between Toyota plants in Japan and their local suppliers. At the other end of the hand-off, trucks carrying small batches of parts from several external suppliers arrived at Georgetown and Toyota's other North American plants frequently. From the perspective of the customer plant, the customer-supplier connection appeared as if the supplier was nearby.

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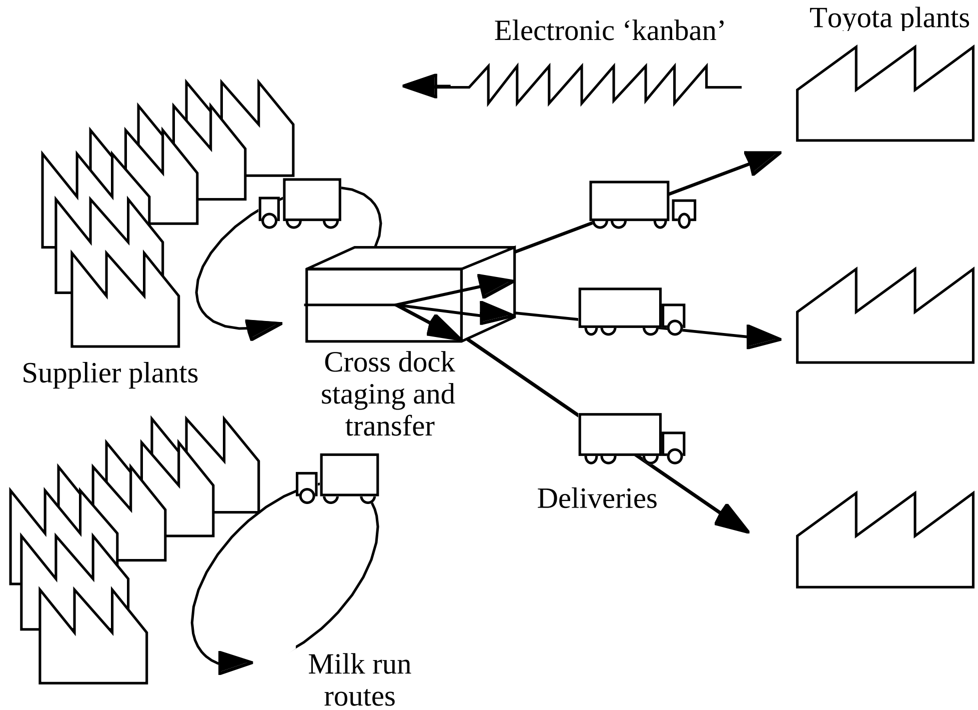
[10] The 'milk-run' approach increased the frequency and reduced the batch-size with which individual suppliers delivered without compromising truckload economics. For instance, if a milk run had ten stops, then each supplier, on average, would be delivering 1/10th of a truckload every hour rather than a full truckload every ten hours. This reduced the inventory required at the supplier plant and at the customer plant and had the added effect of keeping the supplier plant more closely linked to the production pace and sequence of the customer plant. In fact, in some Toyota plants in Japan, deliveries were so frequent and batches so small, that some parts were not unloaded and temporarily stored in a staging area. Rather, they were taken directly to the small line-side stores where they were used within the hour.

[11] Source: Interview with Ypsilanti facility managers during site visit.

The mechanisms for ordering supplies were different, however, because of the longer travel distances between Toyota's plants and those of its suppliers. Longer supply lines required faster order processing, and this was done electronically. Essentially, electronic kanban cards were identical in function to the physical kanban cards used by Aisin. For example, a batch of electronic cards (a) was the sole means of requesting new parts, (b) was sent for every order shipment, (c) went from a specific customer plant to a specific supplier plant, and (d) established the mix and volume criteria for assessing if an order was correct.

Milk-run trucks picked up completed orders from suppliers on an established schedule and drove to the cross-dock facility to be unloaded. Parts were staged for pick-up, and, within a few hours, long-haul trucks arrived, were quickly loaded, and sent directly to Toyota (customer) plants. Although the hub of a sprawling and complex supply network, the cross-dock facility had no inventory other than those parts just delivered and awaiting the next shipment out.

Figure 5: Design of the cross-dock facility



6.4 SYSTEM DIAGNOSTICS

Imbedded tests existed for shipment composition (mix and volume) and for shipment timing.

6.4.1 TESTS OF SHIPMENT MIX AND VOLUME

In TPS managed plants, the 'construction' of each shipment was tested to determine that the right mix and volume of product would be ready when the shipment was due to be loaded. For instance, a wheel plant delivering every 15 minutes, would need 15 complete sets, of five wheels per set, ready for each shipment. One approach would be to audit each staged shipment just before it was loaded. The approach that was actually practiced throughout TPS-managed plants was to assign one letter-envelope-sized card per set. The cards were sequenced in a sorting rack according to the order in which they had to be staged for loading. Each card indicated a wheel-set type, and each slot in the rack corresponded to one minute in the 15-minute staging cycle. At the start of each minute, the worker who was loading the shipment would take a card, collect the wheel set to which it corresponded, bring the wheel set to the staging area, and then return to the card-rack to repeat the cycle.

This provided several tests. If the worker took a card and discovered there was no appropriate wheel-set available, he called for help immediately. If the worker came to the rack and discovered that he was behind schedule (i.e., he came to take the 6th of 15 cards and the 7th minute had begun to elapse), he also called for help immediately. Thus, the staging process had imbedded tests to detect immediately if the mix, volume, and timing of the shipment did not meet the criteria established when the customer sent the shipment-order.

6.4.2 TESTS OF SHIPMENT TIMING

Trucks operated according to an established schedule. Checks were built in to determine if the trucks were not arriving at, and departing from, their origins and destinations on time. Plants initiated longer-term corrective actions to reduce cycle-time means and variances. One plant, for instance, saw that some trucks arrived early while others arrived late because drivers entered the grounds of the plant using different access roads. This caused 'blocking' and 'starving' at receiving. Trials were conducted to discover which routes were preferable, given concerns about congestion at receiving bays. Trucks were then assigned routes to reduce variability.

It was also discovered that one supplier's drivers were lifting returned, defective truck-wheels several feet into their truck cabs. Lifting and unloading took time and imposed ergonomic strains, and traveling with 70-pound wheels in the driver's cab was unsafe. In response, each truck was outfitted with a basket on its front grill so that returned wheels could be lifted quickly and easily. This reduced both the cycle time mean and variation while reducing ergonomic and safety risks.

There was an additional nuance. The basket was designed to hold one wheel only. Therefore, like the stores at Aisin, this element of the system accepted some process variability. But variability above a specified range (i.e., the return of more than one wheel per shipment) triggered problem solving.[12]

[12] Source: Plant visit and presentation by process improvement team.

7 Discussion: Value of direct, unambiguous, self-diagnostic connections

'Customers' at Aisin could directly control the production pace of their immediate suppliers, a JIT attribute widely discussed in the literature. The same was true of customer and supplier plants linked through Toyota's cross-dock facility. Beyond this, Toyota affiliates used JIT to secure benefits from problem solving and process improvement. In the Aisin and the cross-dock cases, direct control was possible because customers and suppliers were linked through connections that were *specified* in terms of who should get what from whom, how requests should be made, and the correct form, timing, and quantity of supplier responses. *Imbedded tests* in these connections signaled immediately when request-response hand-offs did not occur as expected, and these signals triggered *problem-solving* close in time, place, and person to problem occurrences.

Combining specification with testing and improvement may remind many readers of favorable commentaries on standardized work which: '… is not necessarily a weapon used by management to extract maximal effort from a recalcitrant work force.' Rather, '… the knowledge required to make improvement can be used … by the joint efforts of workers, managers, and engineers to fuel continuous improvement of efficiency and quality without intensifying work beyond worker's capacities' [Adler and Cole, (1993)]. Toyota and its best affiliates, such as Aisin, employ standardization (specification) as the basis for improvement, both for individual work in a larger system, and for the connections through which individual work is linked into a larger system. Thus, JIT within TPS-managed organizations is not a tool for static optimization. Rather, TPS/JIT repeatedly tests and improves the mechanisms by which individual efforts are combined into a whole.

There are additional nuances. In general, feedback loops detect when design assumptions are invalid and must be updated. However, feedback is compromised by information lags, confounding of parameters, system noise, etc. [Ogata (1990)]. Production systems suffer these problems. Information loses value for problem solving specifically and decision making more generally when it is moved out of time, place, and person context [Leonard and Rayport (1997), MacDuffie (1997), von Hippel (1994), von Hippel and Tyre (1995)]. System complexity, process opacity, and information perishability make it desirable to design work-systems in which discrepancies between expected and actual results prompt problem solving, thereby advancing ‘stages of knowledge about production’ that can be exploited [Jaikumar and Bohn (1992)].[13, 14]

The just-in-time techniques used for process control and feedback consistently by Aisin, specifically, and Toyota more generally, appeared to account for the inherent context-specific nature of information and the incompleteness of knowledge with which work systems must be managed. JIT connection tests -- from very small to very large levels of aggregation -- were frequent; they evaluated every hand-off every time and, because tests were imbedded in the doing of work, provided rapid feedback. Also, because the tests were built in, identification and response to problems were close in time, person, and place to their occurrence.

Existing theories of process improvement, cited above, and observations at Aisin specifically and Toyota more generally of managing complex work-systems to foster problem identification and improvement lead to the following assertions.

- For problem solving to be an integral part of an operating system, problems must be identified close to their occurrence in time, place, and person.
- This requires that work be designed with imbedded tests that trigger particular people to solve particular problems as they arise.
- To imbed tests in connections, there must be unambiguous specifications of how customers make requests and how suppliers provide responses, so that comparisons between requests and responses can generate unambiguous signals that a problem has occurred.
- To specify how particular customers will make unambiguous requests and how specific suppliers will provide unambiguous responses for particular products, services, and information, pathways must be specified in terms of who will get what product, service, or information from whom.

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[13] ‘Discrepancy’ is used here rather than ‘contingency’, the term used by Jaikumar and Bohn, to avoid confusion between their meaning and that of Lawrence and Lorsch, cited earlier.

[14] Jaikumar and Bohn describe various knowledge stages. The lowest stage is being able to recognize good output but not control parameters. The highest is being able to recognize, discriminate, and control primary and secondary variables allowing ‘complete proceduralization’.

8 CONCLUSIONS

As just discussed, it is consistent with existing theory to assert that imbedding self-diagnostic tests into work-systems to trigger immediate problem solving can be the basis for continuous improvement and sustained, outstanding operational performance.

Over what range of products, processes, or industries, then, might these approaches be effective? Jaikumar and Bohn based their 'dynamic approach' for managing on observations at a mass-market watchmaker, where knowledge already seemed to be at a relatively high stage. Production was automated and ran continuously with uptime of 99.8% and scrap plus rework at 1% of material cost. Yet, even at these enviable levels, the authors recognized opportunities for problem-solving-based process improvement. Toyota consistently has been its industry's benchmark in terms of quality, flexibility, and efficiency. Yet, it too dynamically manages work systems to further advance its process knowledge and further improve its performance.

This suggests testing the approaches outlined in this paper where knowledge is even less advanced and processes are even less reliable rather than where processes are more completely proceduralized. For those who have understood JIT as committed to zero-inventories, instant responses, and intolerant of process instability, this is counter-intuitive. However, exciting opportunities are opened by recognizing the knowledge-building dynamic fostered by integrating tightly the doing of work with problem solving and improvement.

For example, for some semiconductor makers, product and process complexity lead to low yields, high inventory, and long lead times.[15] For health care providers, idiosyncratic patient-conditions and reliance on skilled labor rather than automation complicate 'proceduralization' [Tucker, Edmondson, and Spear (2002)]. Thus, there is potential in examining other industries to see if designing work-systems with imbedded tests that immediately trigger problem-solving can help accumulate knowledge and achieve superior performance.

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[15] Source: Site visits by the author to three semiconductor fabrication facilities in 2000.

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