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THE HIGH-VELOCITY EDGE

HOW MARKET LEADERS LEVERAGE OPERATIONAL EXCELLENCE *TO BEAT THE COMPETITION*

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FIVE-TIME SHINGO PRIZE AWARD WINNER

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In memory of
Jacob Irgang (1930–1995),
Korean War veteran, Purple Heart recipient,
Stuyvesant High School teacher extraordinaire, 1963–1995.
He knew his students were capable of far more
than even they realized.

CHAPTER 6

CAPABILITY 1: SYSTEM DESIGN AND OPERATION

How Toyota Raced from Behind to Win

We have looked at instances in which several organizations do the same or very similar work under the same or very similar external conditions, but somehow one races ahead of the pack. Southwest beats the other airlines. The U.S. Navy runs a nuclear reactor program with a safety record which neither NASA nor the Soviet Navy can match. Alcoa generates great economic returns while creating a remarkably safe work environment. Then there are the companies that manage to accelerate themselves out of their troubles, such as Pratt & Whitney and Avenue A.

Toyota is undoubtedly one of these high-velocity organizations, starting off far behind the American Big Three when it first entered the U.S. market and racing ahead to become the world's most successful automaker, with "the healthiest profits in the industry." As *Fortune* wrote when putting Toyota on its 2007 list of the most admired companies:

> You may recall that 25 years ago, it was just one of a herd of Asian interlopers selling fuel-efficient econoboxes, and Detroit snickered at the notion that Americans would ever want to buy many of them. As everyone now knows, that crystal ball was cloudy: Toyota's Camry has been the bestselling car in the U.S. since 2002, and the Lexus LS 430 has been the leading luxury-car brand for seven straight years. The company's long-term strategy is as green as anyone's. Sales of the Prius, which runs on a gas-electric hybrid engine, passed 100,000 units in 2006. The Prius is today as de rigueur in Hollywood as the hydrocarbon-swilling Hummer used to be.

And there's no doubt that Toyota's success is largely attributable to its "velocity of discovery"—the speed with which the company improves, innovates, and invents. Marvin Lieberman and his coauthors compared changes in productivity at the large automakers from the 1950s to 1987. They found that Toyota outstripped its competitors on improvements in manufacturing labor productivity. But it wasn't the usual matter of investing more heavily in plant and equipment—replacing human labor with mechanical labor. Rather, Toyota's capital productivity also outpaced the sector. In short, Toyota was discovering how to do ever more work, more quickly and more reliably, without using more labor or more machinery—and this process of discovery kept going decade after decade. In a separate study, Lieberman and Dhawan pointed to the durability of competitive advantage rooted in the way an organization conducts its work, even if the work it chooses to do is similar to that of others in the marketplace. Those authors found that the traditional sources of competitive advantage—differentiation and protected market niches—are not effective in the auto industry. Furthermore, when Lieberman and Dhawan compared the leading U.S. and Japanese automakers, they found that, in terms of operational effectiveness, "lagging firms have converged only slowly to industry best practices (if at all), while stronger firms like Toyota have made continual advances, thereby maintaining or expanding their lead."

Toyota's advances, which Lieberman measured at an aggregated level, come from a myriad of specific improvements that are across the board. For instance, in the 1940s, Taichi Ohno, one of the seminal contributors to the development of the Toyota Production System, became frustrated that it took stamping press operators two to three hours for a setup; that is, to shift from making one kind of part to making another kind. By the 1950s, setups consistently took less than an hour; and in the 1960s, they were often down to three minutes. Workers were not simply doing the same thing more quickly, like galley slaves responding to a quickening drumbeat; they were continually discovering better ways to perform the setup.

Charles Fishman, writing in the magazine *Fast Company*, reports on a process of incessant discovery in Toyota's paint shops. Painting cars had been a well-studied challenge ever since Henry Ford's day, yet Toyota pushed to discover new ways to lower cost, improve quality, respond more quickly to customers' wishes, and reduce risk to its employees and damage to the environment. In the initiative about which Fishman writes, the shops switched from feeding paint through hoses, which needed flushing with every color, to using refillable cartridges that could be interchanged from one car to the next. Of course, switching a cartridge was much faster than flushing a hose, but that wasn't all. When a hose was flushed, there was a lot of paint still in it; it turned out that as much as 30 percent of the paint which the shop bought had been going to waste. In addition, the shops no longer needed the solvent used to flush the lines; this not only saved money but eliminated a safety and environmental risk. As the plant could paint any color in any order, it no longer had to batch cars to reduce paint waste; this allowed a smoother flow of production from the body and weld shop through the paint shop and on to final assembly. Paint booths that had previously painted 33 cars per hour could now paint 50. One of the three booths was shut down and dismantled because it was no longer needed, which in turn freed up space in the shop.

We have already seen that not all high-velocity organizations are involved in manufacturing. But even within a manufacturing company, the practice of continual, disciplined, accelerated discovery applies to everything the company does, not just to its manufacturing operations. At Toyota, for example, we can see high velocity in the firm's creation of new brands as well as in its manufacturing. In the 1980s, Toyota was already looking beyond the success of its small and mid-sized cars, setting the stage for a luxury brand. Introduced in the 1989 model year, Lexus was dubbed "the imported car of the year" in 1990 by the Motoring Press Association. By 1991, Lexus was introducing new models to round out its offerings, and by 1992, it was outselling Mercedes and BMW in the United States. On the other end of the brand spectrum, Toyota, like many automakers, had been having trouble in younger market segments. But the company overcame that obstacle by inventing the successful Scion brand, with its funky styling and hip customization options.

Though many automakers have complained about the impossibility of dramatically increasing fuel efficiency, promising "silver bullet" solutions such as fuel cells and electronic propulsion that always seemed just a few more years away, Toyota launched the Prius with its hybrid-drive system, establishing the company as the leader in fuel efficiency without compromising performance or reliability. The hybrid-drive technology that Prius pioneered is now available across much of Toyota's product line and has had more than 1 million units sold.

Generating High Velocity: The Legacies of Taiichi Ohno and Sakichi Toyoda

Toyota's long history of success is founded on a commitment to seeing each piece of work as part of a whole process and by an equal commitment to discovering better ways to do work rather than succumbing to acceptance of the unsatisfactory or complacency with the successful. This is precisely what high-velocity organizations do and what those who chase them don't do. In Toyota's case, these two commitments have their roots in two corporate luminaries, Taiichi Ohno and Sakichi Toyoda.

Ohno is rightly famous for developing and deploying just-in-time "pull" production. In creating this system, which has since been surrounded (and often obscured) by a fascination with particular shop-floor control tools, Ohno was tackling a basic problem in modern enterprises: ensuring that the pieces of a larger whole are harmoniously synchronized rather than discordant.

After World War II, American automakers were eager to reenter the Japanese market. Only a slight twitch of their enormous productive capacity would have proven overwhelming. Japanese automakers were hardly in a position to fend off such competition; everything they needed—labor, equipment, and materials—was in short supply in postwar Japan. Ohno was managing in a Toyota engine plant, trying to make a go of it, but frustrated. As he looked around the plant, there was a worker diligently manufacturing parts, which just sat there waiting to be used. And there was another worker and his machine, doing nothing because he didn't have the parts he needed. Finally, more or less out of the blue, the parts he needed would turn up and he would get to work. Meanwhile that first worker, having built up an enormous pile of parts, had nothing to do.

How could an operation this wasteful of its men, machines, and supplies ever fend off Ford and GM? Ohno developed a simple rule to make sure that the pieces acted together in a self-regulating synchronization: If someone—the "customer"—needed something, he had to go ask for it, and the "supplier" was not allowed to produce and deliver something until asked. The objective was to ensure that those upstream did what those downstream needed and *only* what those downstream needed—no stockpiling on one end and no waiting around on the other end.

Of course, adherence to this rule in its most absolute form would be too much. To accommodate process times, people might keep a small store of material which gets replenished or produce in batches of a few rather than one. To accommodate the distance between a customer and supplier, requests might be conveyed by cards or electronically rather than in person. An intermediary might have the job of moving requests from customers and carrying the responses back from the suppliers. But the basic algorithm holds. Needs downstream pace work upstream so individual work is *in service to the larger process and ultimately all are linked in service to the end customer, none acting in isolation*.

Sakichi Toyoda, founder of the Toyoda Automatic Loom Works from which the Toyota Motor Company sprang, began his career during the years after Japan opened to Western trade and commerce after centuries of isolation. The way I have heard the story repeated within Toyota, women in his village, including his own mother and grandmother, wove fabric for clothing on hand-powered looms, which was hard labor. Toyoda observed that they faced a heartbreaking predicament. If one of the hundreds of threads on the loom snapped, it created a run in the material. Most of the time, the weaver wouldn't know this had happened and would continue to weave, inadvertently creating material more appropriate for rags than clothing.

To solve this problem, Toyoda committed himself to inventing a loom that would automatically stop the moment a strand broke. He dubbed the idea that work should stop when and where a problem occurred *jidoka* (which was translated into English as *autonomation*, meaning "self-regulation"). The loom was a success, and the *jidoka* concept was so compelling—building in the assurance that all work is the work that is intended and won't produce scrap—that he eventually sold rights to the patents to the British textile industry. With this revenue, he started the automotive company. Just as Ohno's innovation led to the insistence that the parts of a system always be seen as part of a whole, Toyoda's *jidoka* concept became embodied in the idea that work should be designed so problems are evident when and where they occur. Seeing problems was the prerequisite for the high-speed *kaizen* ("continuous improvement") for which Toyota came to be so highly regarded.

A Framework for Designing Systems

With Toyota's record of success in mind, let's take a look at how the company achieves it. I will repeat my key point: High-velocity organizations can sustain their high performance—staying ahead of competitors or beating seemingly impossible odds—because they achieve that high performance in a particular way, using the four capabilities necessary for managing complex operations. We have already observed these capabilities in some detail at Alcoa and in the U.S. Navy. Now we'll look at the first of these—how systems are designed and operated—at Toyota.

To do so, we first will look at a simple but exceptionally resilient framework for process design. With that under our belts, we'll look at some examples, beginning with the application of that framework to the work of one individual doing one job on a Toyota assembly line and to the on-the-job training he or she receives for that specific job. Then we'll expand our view to the process by which new hires at a Toyota plant in the United States are prepared for assembly-line work prior to their specific on-the-job training for a specific line job. Then we'll take an even wider view, applying our framework for process design to an entire manufacturing system. Finally, we'll see how this framework applies not only to the design of an operation, but also to the design of the process of designing an operation. Put another way, the approach which is used by managers at Toyota to design a line worker's work is the very same approach used to design an entire system of work.

In 1995, I was visiting a computer-equipment plant. Among the other visitors was Hajime Ohba, general manager of Toyota's Supplier Support Center. Our tour hosts proceeded logically (so I thought) from receiving to shipping, allowing us to see a variety of whiz-bang technologies along the way. Tellingly, the executives from corporate who were along for the walk could not have been less interested. It seemed as though they had seen it all before and that they spent more time talking about their latest fishing trip than paying attention to what was being said. At each stop, Mr. Ohba would ask the shop-floor employees a series of questions that seemed rather bland but, as I discovered later, were of great substance. When we returned to the conference room, our hosts, almost as a courtesy, asked him for his thoughts on what he had seen.

In what seemed an instant, Mr. Ohba sketched a schematic of the plant's production system—its key process steps and flows of material and information—along with his observations about work methods. Then, without hesitation, he presented a long list of things that inevitably had to go wrong:

scrap here, bottlenecks there, missed defects, lags, delays. Not that he had actually seen any of these problems, mind you; he just knew they had to be happening. His analysis was so on target that the executives, who previously had not been paying attention, took out paper, pens, and reading glasses and began taking copious notes.

A fluke, I thought. But the next day we visited another plant, and the same thing happened. During the next several months, Mr. Ohba and I kept meeting each other in different facilities. It was the same story every time.

At first, I attributed Mr. Ohba's ability to characterize and diagnose complex work systems to his decades of experience running production facilities, supporting start-ups, and working with suppliers. With so much exposure to best practices, he could easily spot how other plants fell short. But that didn't explain how he could appraise any production process so quickly and astutely, even when product, process, or market was unfamiliar to him.

It took time, but I came to realize that he was not simply benchmarking against the hundreds if not thousands of analogies and cases he had seen. Burrowing through my research notes, I discovered a consistent pattern. Wherever we were, whatever we were observing, Mr. Ohba asked the same questions. His wide experience had helped him develop a robust framework for understanding and diagnosing the design of any complex work system. It was this framework, not necessarily benchmarking against particular situations, that he was calling on to perform his magic. It was this framework that gave him this ability to characterize and diagnosis complex systems, even those of which so much was unfamiliar. As my research continued, I had another realization: His most experienced colleagues at Toyota were all working from the same framework. It did not matter if they came from human resources, production, engineering, logistics, or administration; they had a shared way of thinking about system design and improvement—a real advantage, I learned, when it came to working on problems together.

What were those questions, and what was their purpose? No matter where we were, Mr. Ohba always started by asking if he could start his investigation in shipping, normally the last (and seemingly least interesting) stop on the guided tour. There he found the person responsible for loading trucks that day—not the person who managed shipping but the guy or gal who did the hands-on lifting and loading—and asked that person how much of which products was being shipped to whom and at what time. He was eager to know what it meant for the plant to be successful on that day and how one could tell if success had been achieved or not.

Having learned that, he asked where the boxes that had to be shipped were and then walked to the last packing station. There he asked that worker where the materials he or she needed came from. Continually asking that set of questions—What are you doing? From where did you get what you needed?—he made his way "back" through the plant. This helped him establish what steps were necessary and who was responsible for performing them in order to ship products successfully.

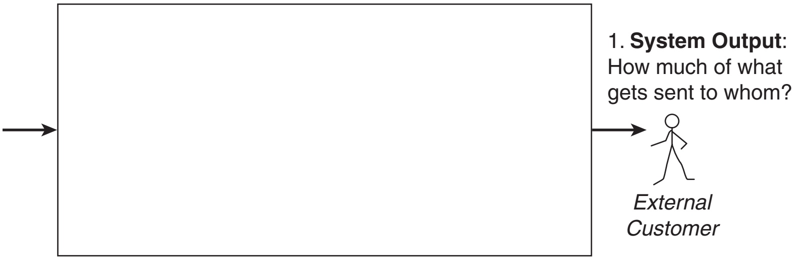
In fact, at each stop he asked another layer of questions: What signals you to begin your work—a production instruction, a supervisor's instruction? How to you respond to that signal? What is the mix, volume, container, and timing of your response? Similarly, how do you signal that you need something? What happens when you do?

Having established precisely when and how material, information, or assistance is handed off from one step to the next—the linkages—he typically would ask one or two workers if he could observe how they did the work for which they were responsible. He wanted to know not only how things were done successfully, but how people knew when things were *not* working well.

I realized that Mr. Ohba had a simple, hierarchical, very robust way of thinking about the design of complex work systems, as I summarize and illustrate, below. (Figures 6-1 through 6-4 show very simple linear flows and handoffs from one person to the next with no intermediaries and no manufacturing resource planning, enterprise resource planning, or other centralized information flow system. This is deliberate, but it does not mean that Mr. Ohba's questions do not apply to more complex situations. In fact, asking these questions in this order helps reveal the complexity of a system with great clarity.)

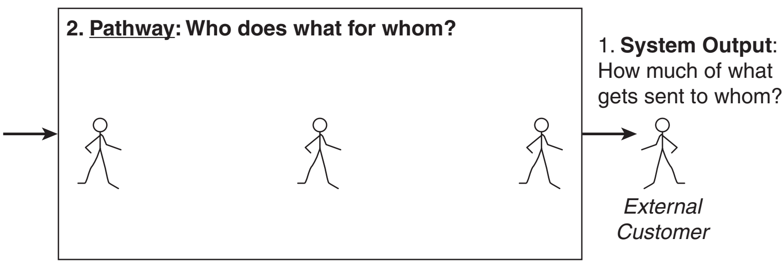
1. *System output.* First, he had to know the objective of the system overall. What does it have to deliver, to whom, and by when to be successful? That was why he wanted to start in shipping. It was as close to the actual customer as he could get, the place where it was most clear what had to happen to be successful and whether or not it had happened. (See Figure 6-1.)

Figure 6-1 Design levels: System



2. *Pathway design: flow of materials, information, and services.* Second, he wanted to know the architecture of the system. Who has to be responsible and perform what steps in what sequence in order to achieve the system's overall output? By knowing this, he would know the pathways over which materials, services, and information flowed from start to finish. (See Figure 6-2.)

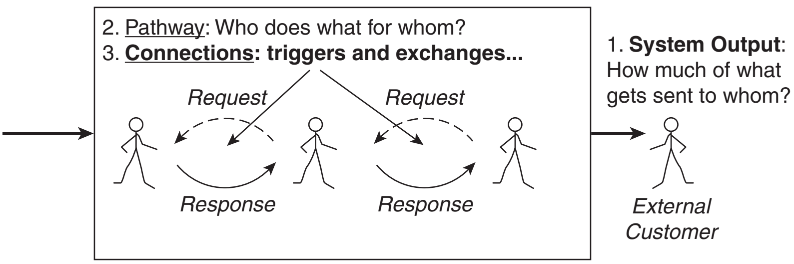
Figure 6-2 Design levels: Pathway



3. *Connection design: linkages between adjacent process steps.* Third, he wanted to know how people responsible for steps on a pathway were connected by handoffs or exchanges of information, material, and services, with particular attention to

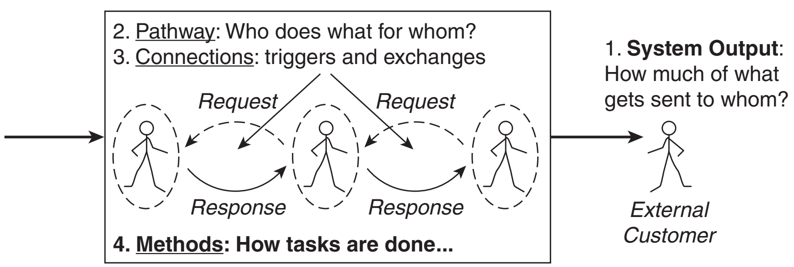
information that triggered people to do what they had to. What are the form and the source of the information that signals someone to start and stop his or her work? Conversely, how does someone indicate what he or she needs in order to proceed? In reaction to those requests, what form do products, services, or information take as they are handed off from someone at the pathway steps at which they are created to someone at the steps at which they are used? (See Figure 6-3.)

Figure 6-3 Design levels: Connections



4. *Methods for individual task activities*. Fourth, he wanted to know how people actually did the work for which they were responsible. For each particular task, what steps

Figure 6-4 Design levels: Methods



must the worker perform, in what order, at what time and location, and with what results, in order to do that task successfully? (See Figure 6-4.)

HOW THE CAPABILITIES CORRESPOND TO RULES IN USE

Some readers may be familiar with a 1999 *Harvard Business Review* article I coauthored with Kent Bowen, "Decoding the DNA of the Toyota Production System," in which we described the four "rules in use" fundamental to the Toyota Production System. Here is how those four rules map onto the four capabilities presented in *The High-Velocity Edge*. The first three rules concerned process design and operation: how to design and operate a pathway (simple and specified), a connection (direct between immediate customers and suppliers and with unambiguous, binary mechanisms for sending requests and responses), and work activities (specified in terms of work content, sequence, location, timing, and outcome). These are embodied in *The High-Velocity Edge*'s Capability 1. Since that time I have come to understand the necessity of specifying the expected output of an operation with an embedded test to indicate whether you are ahead of or behind that expectation. Hence the need for a fourth level of design.

The fourth of our rules in use—that problem-solving should occur in the smallest possible group, using the scientific method with the support of a leader—is the core of *The High-Velocity Edge*'s Capability 2—swarming, containing, and solving problems when and where they occurred with those who were affected. Capability 3—sharing knowledge—was touched on in the 1999 article, and Capability 4 (developing Capabilities 1, 2, and 3) was only alluded to.

It was not enough that the design of outputs, pathways, connections, and activities be well specified. Recall Sakichi Toyoda's principle that if a thread on a mechanical loom broke, the loom should stop immediately so the operator wouldn't waste time and effort weaving material that had a run in it. His approach is embodied throughout Toyota in the principle that work cannot be performed unless a built-in test is incorporated that will immediately signal when something has gone wrong and where it has gone wrong. There are tests appropriate to each level of the four levels of system design:

1. *Outputs*. How do you know if your shipments are running ahead or behind?
2. *Pathways*. How do you know if all the process steps have been completed, each by the person who was responsible?
3. *Connections*. How do you know if you are ahead or behind in fulfilling requests from immediate "customers" and getting what you need from immediate "suppliers"?
4. *Activity Methods*. How do you know if the method you are using to complete this task is working?

Table 6-1 summarizes this framework.

Table 6-1 Summary of System Design and Operation Framework

	Specified in Terms of	*Built-in Test Indicates*
System output: Matching supply with demand	• How much of what has to be delivered to whom by when for success?	• If the system is running behind, there is more demand than capacity. • If the system is running ahead, there is more capacity than demand.
Pathway: Assigning responsibility for work in sequence	• What tasks have to be completed by whom in what order to achieve the target output?	• If someone needs to do something unexpectedly, the system is underdesigned or underresourced. • If someone is idle contrary to expectations, the system is overdesigned or overresourced.
	• Is the flow simple and linear (good) or does it loop back on itself (bad)?	• If the flow loops back on itself, problems at one step may flow downstream and then be reinjected in a disruptive, amplifying fashion upstream.

(continued on next page)

Table 6-1 (continued)

	Specified in Terms of	*Built-in Test Indicates*
Connection: Conveying material, information, and services between people responsible for process steps	• What is someone's trigger to start and stop the work for which he or she is responsible, and what is the format of his or her response?	• A request for which there is no response means that a customer's need is going unsatisfied. • A response for which there was no request means that a supplier is working ahead of need.
	• Are requests and responses conveyed directly between immediate customers and suppliers?	• If they are, upstream and downstream process steps will be working in synchronization, with the needs of the downstream step triggering the work of the steps on which it depends. If they are not, dyssynchronization will occur.
Activity Method: Accomplishing work for which one is responsible	• What is each person's work—content, sequence, timing, location, and expected outcome?	• If the work design is not being followed, is there something wrong with it or with the training for it? • If it is being followed but is not achieving its intended objectives, is there something wrong with it or is it being used in the wrong circumstances?

Specifying Work Designs and Building In Tests

We'll now look at several examples of what it means for a process to be highly specified in terms of what is expected to lead to success, with tests built in to indicate when and where the process is not successful. We'll start by looking at a relatively simple example, the work of a single worker and the on-the-job training for that job. The contrasts with my experiences at the Big Three plant, described in Chapter 3, will be abundant. Then, we'll look at the process by which someone is trained before he or she even starts to work on the line. Even though training is less tangible than manufacturing and much more affected by the particular skills, background, and capabilities of each individual, we'll see the same discipline of specification and self-corrective testing being applied. From there, we'll move on to an example of an entire production system and then to two examples of the design of the complex task of designing (or redesigning) an entire production system. I deliberately chose a series of examples that increases in scale and complexity in order to emphasize the fact that the same principles of specifying and building in tests for success are always at work.

Example: Assembly-Line Work

When I worked on the line at a Big Three plant, I was supposed to install right front seats, but it was very hard to know how to do that successfully. I later discovered that I had been working very hard in that plant to accomplish half the work done with far less effort in a Toyota plant.

At Toyota's Kentucky plant (Toyota Motor Manufacturing, Kentucky—TMMK), for example, installing the right front seat had seven distinct prespecified steps. Each step was expected to take a specific amount of time; intermediate tests indicated when the work was not being performed as designed or when the actual outcome failed to match the expected outcome. These are summarized in Table 6-2 and are illustrated in Figure 6-5. They required 46 seconds of work and 5 seconds of walking, thus occupying 51 seconds of the allowed 55-second cycle.

Figure 6-5 Standardized work chart for seat installation at Toyota Kentucky. Hashmarks indicate car position for each second it is in work area.

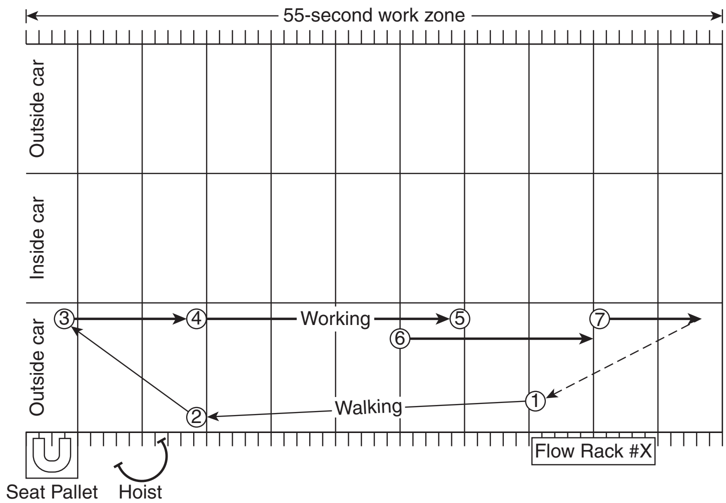


Table 6-2 Standardized Work: Right Front Seat Installation at TMMK

Step	*Description*	*Time (Work/Walk), Seconds*		*Quality Check*	*Safety*
1	Check manifest	2			
2	Set hoist to seat	3			
3	Set seat to door area	6	2	Gun torques out (to prespecified torque) to confirm tightening. Bolt head flat to seat rail.	Team member must be trained to use equipment for safe ergonomics.
	Place rear bolt covers on rear floor and return hoist	4			
4	Install two front seat bolts	14			
5	Adjust seat forward	4	3		
6	Install rear seat bolts	11		Gun torques out (to prespecified torque) to confirm tightening. Bolt head flat to seat rail.	Shoot outside rear bolt with left hand to reduce strain on right hand and elbow.
7	Install bolt covers	7			
	Total	**46**	**5**		

Example: Training Assembly-Line Workers

It wasn't just the shop-floor work which was designed and done differently from the work I had done in the Big Three shop. A new hire's preparation for that work was also worlds apart from my Big Three experience. There, I had been thrown into the thick of things with merely a cursory demonstration offered to the whole group of new hires. At TMMK and other Toyota plants where I observed the training process, new hires were shown each of the steps and then were allowed to perform the first step, with the trainer completing the sequence. This continued until the new hire could consistently perform the first step correctly and in the time indicated. Only after the new hire had passed this test did he or she move on to the second step, with the trainer completing the remaining five. This process continued until the new hire had mastered the entire sequence.

Consider the implications of teaching in a step-by-step fashion, with the worker not advancing until the preceding step has been mastered. Whereas my problems were spread out over a 57-second interval, the problems of a trainee at TMMK are confined to the few seconds needed to complete the one step which he or she is learning. Because the training process is designed, performed, and controlled with finer granularity, responses to problems have greater resolution and control. When teaching me, Bill had to be able to detect and respond to problems at any point in the work cycle. If he had been training me in a step-by-step fashion, he would have been able to concentrate his attention and his efforts more precisely.

The differences did not end (or start) there. Even before the step-by-step on-the-job training, new hires at Toyota go through an equally well-scripted onboarding process to prepare them for their on-the-job training on the assembly line. I investigated this myself at Toyota's Indiana truck and van assembly plant. Each step was designed with the needs of the next step in mind. Just as the overall objective (output) of the on-the-job training is to prepare a new hire for a particular line job, the overall objective (output) of the onboarding process is to prepare new hires to learn on the line. How this was to be accomplished was scripted and specified in detail, with tests indicating if someone had successfully completed one stage and was ready to progress to the next. It was the same principles yet again.

How was the output of the onboarding process defined? The process should deliver a person who wants to do the line work; who is physically capable of doing it—with the strength for the job, the endurance to keep it up for an entire shift, and the muscular flexibility needed to avoid repetitive stress problems; who has sufficient technical skill to handle materials and use tools safely and effectively; and who has a knowledge of basic shop-floor tools such as just-in-time pull systems to replenish material, andon cords to call for help, and standardized work to complete tasks. If a new hire emerges from the onboarding process without all these characteristics (that is, if the output is not what has been specified), he or she will be unprepared for the on-the-job training and for the actual work that will follow.

To make it easier for the new hire to master his or her new job on the line, and to make it easier for the team leader to train that new hire, human resources makes sure that many skills and attitudes are already in place. For example, even before new hires begin training for their production jobs, Toyota makes sure that they know what they are getting into. To accomplish this, an old gym was converted into a mock assembly line (1 in Figure 6-6). Job applicants spend several hours doing assembly work on mock-ups. In the spirit of continuous improvement, the original day-long mock-up session was extended to two days when Toyota discovered that it was important to find out how a new hire reacted to putting in a hard day on the line and then coming back the next day to do it again. Not everyone found that tolerable, and Toyota did not want to assign a new hire to a job in which he or she was likely to fail.

After the mock-up comes classroom orientation, with a curriculum specific to the job for which the new hires were preparing and with written and practical tests to ensure that the various teaching points had been learned (2 in Figure 6-6). There was nothing like this for new hires at the Big Three plant.

With this portion of the onboard training confirmed, it was on to the next phase—basic-shop floor production-control tools such as standard work and pull systems (3 in Figure 6-6). HR had no intention of leaving new hires to learn these things on the job, consuming the attention of a team leader and perhaps a group leader who was also responsible for other people doing actual production. (This would be a bit like giving kids their driver's licenses and then letting the cops give them driver's ed along with their speeding tickets.) Instead, Toyota created a scaled-down, tabletop model assembly line, on which the product would be miniature trucks made from Legos.

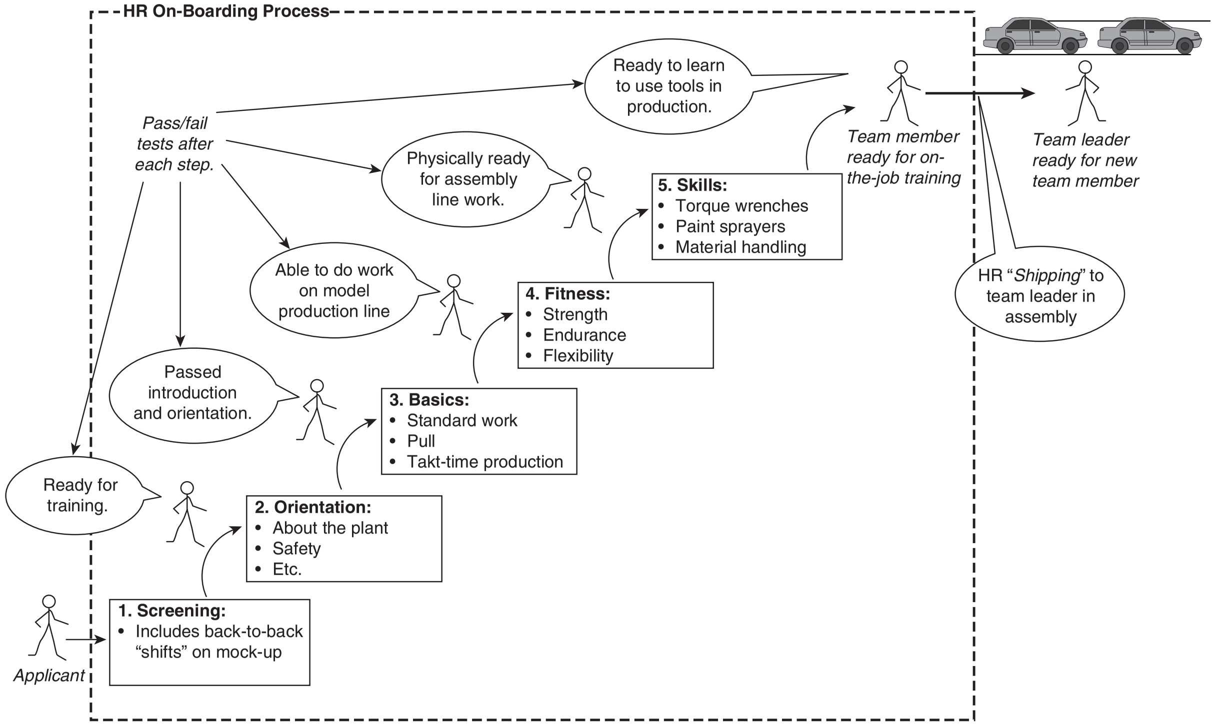
There were many skills to learn, including reading manifests to know what work must be done, using standardized work procedures to accomplish that work, using kanban cards to request parts and materials, detecting errors, using andon cords to call for assistance, and takt-time production to keep up with the rate of customer demand. But the process was brilliantly designed. The complexity of real products, real production demands, and a real production pace was removed so that only one skill had to be mastered at a time. The "student" was always focused on the teaching point at hand, while cumulatively building expertise. (In Chapter 11, we'll see the stark contrast between this approach to training and the approach typical in medical education.)

But still there was more. Assembly line work is *hard* work. It requires strength, endurance, and a good amount of dexterity. So the Toyota Indiana plant had its own aerobics studio (4 in Figure 6-6). The people in the group of new hires whom I met came in quite a variety of sizes, shapes, and conditions, all of them huffing and puffing their way to fitness on exercise bikes, treadmills, and stair-climbing machines.

Finally, there were specific technical skills that had to be mastered (5 in Figure 6-6). In a screened area of the production floor, new hires had a chance to practice shooting bolts, handling parts, and using paint sprayers, becoming competent with the physical tools of their work before they began working on real cars and trucks for which customers were going to pay real money.

Once a new hire had passed all of the tests, he or she would be eligible and *ready* for on-the-job training for an assembly-line job, like the one described just before. There was no pre-

Figure 6-6 Training pathway for new hires at Toyota Kentucky



specified length of time for this training, but there was a specified outcome: New hires were to be trained until they could pass. No one was "socially promoted" and few washed out.

All this elaborate effort to determine what people needed to know to start their jobs successfully and to build a process that would ensure that they had those skills was not limited to shop-floor production work. For those joining the production engineering, equipment maintenance, and other technical departments, Toyota had contracted with a local college to develop training in electronics and other skilled trades. This was conducted along the same lines: Build knowledge in an incremental, layered fashion, rather than fully immersing someone in the real work environment all at once, and build tests into the training so that one stage is learned before the next is tackled.

I have described the training process in such detail because it is important to understand that high-velocity organizations do *everything* in this deliberate yet high-velocity way. Toyota makes cars, but it is as important that the training process be as rigorously defined by its output, pathways, handoffs, and work methods—with tests built in to tell when something wasn't succeeding—as it is that the auto-manufacturing process itself be rigorously specified with *jidoka* (built-in-tests for self-regulation).

To illustrate the concept of designing systems of work with specificity and built-in tests, we started with relatively simple examples: the daily, repetitive work of an individual assembly worker and the on-the-job training he or she would receive. Then we looked at a more complex process involving more stages and more people—the preparation a new hire would receive as a prerequisite to being trained to do his or her work on the line. Now let's look at the same principles applied on a still larger scale.

Example: Managing High-Volume Mass-Customized Production

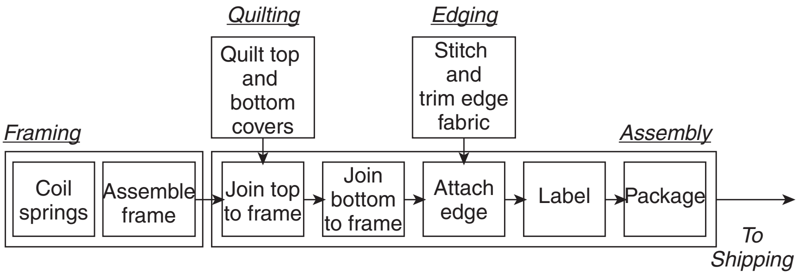
Aisin, a first-tier supplier of auto parts to Toyota, also has a consumer products division. In 1987, its Seiki factory, which manufactured mattresses, switched from mass production to mass *customized* production. Customers in furniture stores could test model beds and specify the size, cover fabric, lining material, quilting pattern, trim color, and firmness for a total of 850 alternatives and then have their customized mattress delivered in three days. This should have been a much harder operation to manage than simple mass production of fewer alternatives delivered with a longer delay, yet Aisin achieved remarkable increases in volume, variety, and productivity with simultaneous reductions in lead time and inventory, as shown in Table 6-3. What did Aisin do to achieve this enviable combination of variety, cost, and short lead time?

Like any product, mattresses are made in distinct steps (as shown in Figure 6-7), all of which are subject to fluctuations in demand, variations in process time, and other perturbations. In the framing stage, springs are coiled and joined into a frame. In quilting, liner layers are sewn to cover layers. In edging, the bolt of material for the circumference of a mattress is stitched. These three subassemblies are assembled into complete mattresses and then labeled, packaged, and shipped.

Table 6-3 Aisin Mattress Production: Variety, Volume, Inventory, and Productivity

	1986	*1988*	*1992*	*1996*	*1997*	*Annualized Rate of Change*
Styles	200	325	670	750	850	14%
Units per day	160	230	360	530	550	12%
Units per person	8	11	13	20	26	11%
Finished goods (days)	30	2.5	1.8	1.5	1.5	–24%
Productivity index	100	138	175	197	208	7%

Figure 6-7 Simplified material flow for mattress production



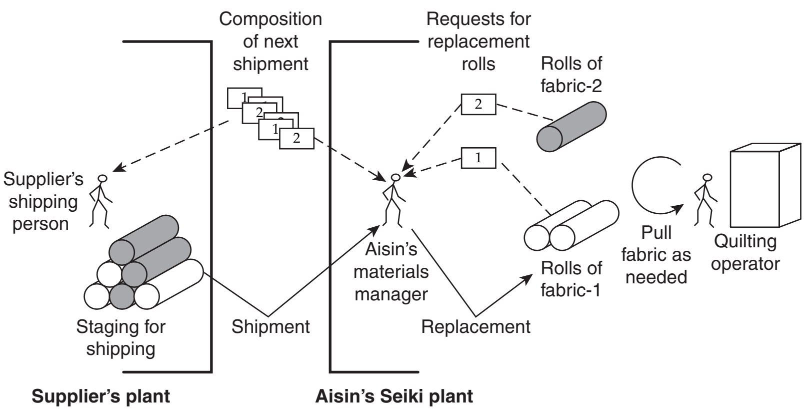
It sounds simple (and compared to jet-engine manufacturing, it is), but the simplicity of the material flows masks the difficulty of having information flow so that the various steps are integrated into a well-functioning process delivering the desired output. Who would think that information flow would matter that much in mattress production or that there even was much information to worry about? In fact, Aisin's success in converting its line from mass production to mass customization came as much from improvements and innovations in the information-processing side as in production methods.

For example, coiling, edging, and the other production centers originally received production schedules from a centralized production control center. Despite the effort that went into planning, these individual production schedules did not necessarily coordinate well. There was often a need for considerable inventory between successive production steps and between the plant and its customers. To solve that problem, Aisin adopted a just-in-time pull system, a method described earlier in this chapter. At Aisin, Taiichi Ohno's simple rule had multiple manifestations. Production schedules had been based on expected (rather than actual) demand. Now, customers would go into furniture stores and design their own mattresses. Those orders would be conveyed to Aisin, where daily production would be set. However, rather than broadcasting detailed production instructions to every work center, production control signaled the last step in the production line that another mattress had to be completed. As each mattress was completed and sent to shipping, the end station signaled the feeder stations (edging, quilting, and framing) to send the next piece forward. When those trigger signals arrived, each feeder station responded by sending one piece forward, now having room to work on the next, pulling on their own suppliers as they depleted material.

We see this simple exchange of trigger signals and material responses for the quilting feeder-line in Figure 6-8.

Why was it so important for Aisin to convert from a push system, in which production control sent detailed instructions to each locality, to a pull system, in which the people at each step set the pace of the steps on which they depended? This gets back to the basic problem of designing complex systems: It is impossible to design them perfectly. When Aisin depended on detailed production schedules, those schedules depended on inevitably flawed predictions of what customers would actually want and reflected flawed predictions of how a complex and therefore unpredictable operation would perform. Once the actual operation began to deviate from the schedule—which it almost always did—people would have to engage in workarounds or firefighting or heroics rather than previously tested best practices.

Figure 6-8 Connecting quilting, material ordering, and material supply



In contrast, letting adjacent steps convey requests and responses directly to each other built self-regulation into the system—no more ad hoc regulation (firefighting) required.

But to be self-regulating, a system has to be both able to see problems and able to correct those problems as they occur. At Aisin this took many forms. For example, every two hours, production control re-established which customer orders were directed to each of the two assembly lines. With clarity of what was expected to be produced, where and by when, it was much easier to track whether the system was meeting those expectations. To highlight problems even further, display boards indicated whether the production lines were ahead of or behind their targets. When they fell behind the target pace, first- and second-level management were signaled to investigate why and to contain the problem.

Those were the diagnostics for the lines taken as a whole. Furthermore, each link between steps had a similar built-in self-diagnostic test. If the quilting subprocess fell out of sync with final assembly, it was obvious within a few minutes. One quilt too few or too many between one step and the other meant the two were no longer operating at the same pace; one had sped up or the other had slowed down. Without this homeostatic ability for self-diagnosis and self-correction, less effective approaches, such as maintaining extra inventory—which would have to be counted, recorded, tracked, and rotated—would have been needed to maintain a steady level of production.

To create this self-regulating, self-correcting capacity, Aisin had to make other design-related decisions. In order to have one process step pace the previous one, it was necessary to specify which people using which machines were supplying which other people. Thus, the flow of material along a predetermined pathway had to be specified; every person at every step had to know, for every handoff, who would supply him or her and whom he or she had to supply.

This is not an obvious approach for many organizations. For instance, at every step Aisin had more than one machine that could perform the same job: two devices to coil springs and build frames, five machines to prepare the top and bottom quilts, two lines on which the mattresses could be assembled. Since, for example, any of the quilting machines could do any of the quilting work, work flow could have been managed on a first-come, first-served basis the way bank customers get in one line and then go to whichever teller is free (see Figure 6-9). Instead, jobs flowed from one specified location to the next (see Figure 6-10) because Aisin did not want to forfeit the self-regulating (self-diagnostic and self-correcting) features of a work flow in which each step "pulled" what it needed from a specified previous step.

Recall that the basic problem in designing and operating a complex system is that no matter what effort has been put into

Figure 6-9 From any to any

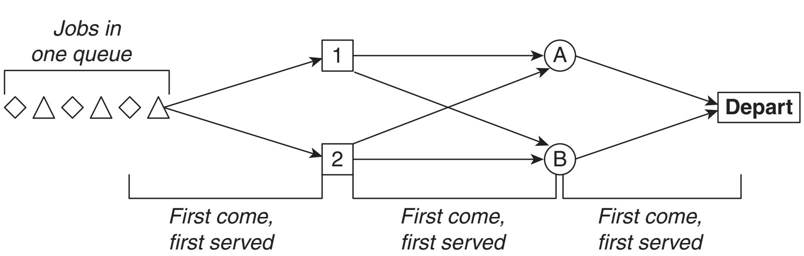
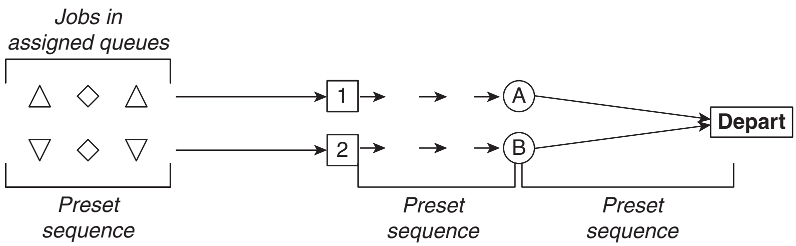


Figure 6-10 Prespecified flow



planning a design, there is still a lot that is not understood about how various elements interact with one another. Specifying the flow of material and information in advance, as shown in Figure 6-10, allows Aisin's designers and operators to be much clearer about their expectations: What steps do we believe are necessary for work to be accomplished? At each step, what are the speed and capabilities of the people using the equipment? At each step, what is the real work content of each job?

By making abundantly clear what is expected to occur, it is much easier to be surprised by the things that happen which have not been anticipated. Does that sound backwards? Shouldn't clarity make it harder to be surprised? The point here is that clear expectations don't, in themselves, make things go right. Clear expectations simply make it obvious when things do *not* go as expected. So it's easier to say, "Oh, that's not what I thought would happen. There is something about this process I don't understand and need to learn." This is exactly what Rickover was after when he insisted that Rockwell "know" how a meeting was going to turn out even before it started. It is the same discipline which Rockwell himself practiced when he insisted that before reactor shielding was tested, estimates be made of what every sensor on the surface would read.

Example: Consolidating Three Production Lines

We have now seen Toyota's *jidoka* approach applied very successfully to the hands-on work of a single individual, to the on-the-job training for a new hire, to the onboarding process for a group of new hires, and to an entire manufacturing operation. The usefulness of clarifying expectations in advance of action and building in tests to recognize when and where those expectations are proven wrong does not stop there. Here is an example of *jidoka* applied to the very opposite of repetitive work performed by an individual or small team; that is, to a complex one-time-only project carried out by a large and mixed group.

A Toyota supplier, facing reduced demand for certain parts, decided to consolidate three lines into one. The production-engineering staff generated a detailed 13-step plan for the consolidation process, indicating who would have to do what work, in what order, with what resources, and in how much time. Why bother with such a tightly choreographed routine for a task that would never have to be done again? Because the team responsible for the consolidation knew that, once the work began, they would start discovering all sorts of things they had not known and demands they had not anticipated. Even in the first step, they realized that certain work had to be performed that they had not thought of and that other work for which they had planned was not necessary. However, they did not content themselves with making do—doing the unexpected work, skipping the unneeded work, and carrying on with the original plan. Instead, every time their script proved to be flawed, they asked themselves what assumptions they had held that had led them to that choice. Typically, they realized that the same assumption was behind other steps in the plan, so they kept revising the later steps on the basis of discoveries made in earlier steps. One might think that specifying in advance what they thought would work and investigating every deviation from those expectations as they did their work would have made this one-off project take longer than necessary. In fact, it allowed the consolidation to be done more quickly, less expensively, and with better results than had been anticipated at first.

Example: New Model Launch

And this is not an isolated example. Paul Adler and his coauthors studied a series of new model introductions at Toyota's NUMMI joint venture with General Motors in California. Toyota was introducing a car to be produced both in the United States and in Japan. Although the car would be the same, much else was different. One plant had been designed by Toyota and operated by the company over many years; the other plant reflected its General Motors heritage in layout and equipment. The workforces had different mixes and degrees of skills and capabilities and the suppliers on which each plant depended were different as well. With so many differences, one approach would have been to let each plant develop its own launch plan. But that would eliminate the opportunity for one plant to learn from the experience of the other.

Toyota decided to have the Japanese plant launch first. As that plant proceeded, it found that what it had anticipated was not always what happened, so it had to continually modify its script. Once that plant's launch was complete, it "loaned" its modified script to NUMMI. Not that the Japanese team felt its script had been modified to perfection, but it did reflect the best current understanding of how to introduce the product successfully. Before the NUMMI team even started its own launch, it modified the Japanese team's script based on what it knew of its own circumstances. Not that they cut out inappropriate segments and improvised to fill the gaps. They replaced those segments with their own tightly scripted segments. As the NUMMI launch proceeded, problems that occurred and were solved along the way prompted additional modifications that allowed for an even more successful launch the next time around.

Having looked closely at how work—from simple and repetitive to complex and infrequent—is designed and operated, we'll turn in Chapter 7 to how imperfect systems are continually improved, as are the people who improve them and as is the body of knowledge that will contribute to further improvement.