Chapter 1

History

Interchangeable Parts

Paris, France, July 1785. It was 18 months after the end of the Revolutionary War in America, and four years before the start of the French Revolution. The need for weapons was on everyone's mind when Honoré Blanc invited high-ranking military men and diplomats to his gunsmith shop in Paris. He had taken apart 50 firing mechanisms (called "locks") and placed the pieces in boxes. The astonished visitors took random parts from the bins, assembled them into locks, and added them to muskets. They found that the parts fit together perfectly. For the first time it seemed possible to make guns out of interchangeable parts.

Thomas Jefferson, a diplomat in Paris at the time, was at the demonstration. The future United States president saw a way to address a big problem in his fledgling country. The United States was facing a shortage of weapons to defend itself and expand its boundaries. If interchangeable parts could be easily produced, then relatively unskilled workers could assemble a lot of guns at low cost, a real boon to the start-up country that had neither the money to buy guns nor the craftsmen to make them.

The challenge of creating a manufacturing process precise enough to make interchangeable parts for guns was taken up by Eli Whitney, who had recently patented the cotton gin. In 1798 Whitney was awarded a government contract to make 10,000 guns in two years. Ten years and several cost overruns later he finally delivered the guns, and even then the parts were not fully interchangeable. Nevertheless, Whitney is considered a central figure in developing the "American system of manufacture," a manufacturing system in which semi-skilled workers use machine tools and precise jigs to make standardized parts that are then assembled into products.

During the 1800s the United States grew dramatically as an industrial power, with much of the credit given to the new manufacturing system. Meanwhile in Europe there was strong resistance to replacing craft production. In France, Honoré Blanc's work was terminated by a government that feared losing its control over manufacturing if unregulated workers could assemble a musket. In England, the inventors of machines that automated both spinning and weaving were attacked by angry crowds who feared losing their jobs. But in America, labor was scarce and there were few craft traditions, so the new industrial model of interchangeable parts took root and flourished.

Interchangeable People

Detroit, USA, January 1914. Henry Ford raised wages of workers from $2.40 for a nine-hour day to $5 for an eight-hour day as he began assembly line production of the Model T. The press suggested that he was crazy, but it was a shrewd move. Ford had taken more than 85 percent of the labor out of a car, so he could well afford to double wages. He had already dropped the price of the car dramatically. Now he drove up wages and shortened work hours to help create a middle class with the time and money to buy automobiles.

It used to take more than 12 hours to assemble an automobile; now it took about 90 minutes. What happened to all of the time? Ford managers applied the ideas of efficiency expert Frederick Winslow Taylor as they designed the production line jobs. Taylor believed that most fixed wage workers spent their time trying to figure out how to work slowly, since being efficient brought no extra pay and could threaten jobs. His approach was to divide the assembly line work into very small steps, and time the workers to uncover the "one best way" to do each step.

Work on the assembly line was boring, repetitive, and tightly controlled. The workers were shown exactly how to do their job and told how much time they had to complete it. They could be trained in ten minutes, and they could be replaced in ten minutes. Like the interchangeable parts of a century earlier, interchangeable workers were at the center of a new industrial model: mass production.

High wages were supposed to make up for the lack of variety and autonomy, and for a while they did. And for a while, things went very well for Ford. Sales soared, and Ford owned the market. But after a while the Model T grew old and an increasingly prosperous middle class wanted to trade in their old cars for more stylish sedans. Ford was slow to respond, because his production system was most efficient when making only one kind of car. Meanwhile at General Motors, Alfred P. Sloan had created an organization structured to produce multiple models aimed at segmented markets. As the demand for variety and complexity grew, Ford's production system grew unwieldy.

Also as time passed workers began to feel trapped in untenable working conditions. They had become accustomed to a high standard of living and were unable to find comparable salaries elsewhere. The widespread labor unrest in the United States in the 1930s is often attributed to a system which held little respect for workers and regarded them as interchangeable.

The Toyodas

Kariya, Japan, February 1927. Toyoda Automatic Loom Works held a workshop for textile engineers to showcase the company's new loom. First the visitors saw how Toyoda looms were manufactured with high precision tools, and then they were taken on a tour of the experimental spinning and weaving facility where 520 of the Toyoda looms were in operation. The looms were a wonder to behold; they ran at a blazingly fast 240 picks per minute and were operated by only 20 weavers. Anticipating a law abolishing nighttime labor, the machines were fully automatic and could run unattended all night. When a shuttle flying across the loom was just about out of thread, a new shuttle replaced it in a smooth, reliable exchange. If even one of the hundreds of warp threads broke or the weft thread ran out, the loom immediately stopped and signaled a weaver to fix the problem.

If you want to understand the Toyota[1] Production System, it is important to appreciate just how difficult it was to develop and manufacture the "perfect loom." Sakichi Toyoda built his first power loom in 1896 and invented an automated shuttle changing device in 1903. A test was set up to compare 50 Toyoda shuttle changing looms with a similar number of simple power looms from Europe. The results were disappointing. These early Toyoda looms were complex, low precision machines that were balky and difficult to maintain.

Sakichi Toyoda recruited technically competent employees and hired an American engineer, Charles A. Francis, to bring the American system of manufacture to his company. Francis redesigned the manufacturing equipment and built a machine tool shop to produce it. He developed standard specifications, produced standardized gauges and jigs, and reorganized the manufacturing line. At the same time, Sakichi Toyoda designed wider all-iron looms, and by 1909 he had patented a superior automated shuttle-change mechanism. Over the next decade, as war distracted Europe and America, looms designed by Sakichi Toyoda sold very well.

1. The "d" in the Toyoda family name was changed to a "t" when the Toyota Motor Company was established. The Japanese characters are similar, but Toyota takes two less brush strokes than Toyoda.

Although Sakichi Toyoda readily adopted high precision interchangeable parts, the loom manufacturing business had no room for interchangeable people. Automatic looms are complex, high precision machines, very sensitive to changes in materials and a challenge to keep running smoothly. Thus, highly skilled weavers were needed to set up and keep 25 or 30 machines running at once. If running a loom required skill, the design and manufacture of automated looms was even more demanding. Sakichi Toyoda had a reputation for hiring some of the most capable engineers being trained at Japanese universities. He kept his development team intact even as he started new companies, and he depended on them to carry on research in loom design and manufacture.

In 1921 Sakichi Toyoda's son Kiichiro joined his father's company and focused on advancing loom automation. In 1924 they jointly filed a patent for an improved automatic shuttle-change mechanism. The research team also developed methods to detect problems and stop the loom, so that looms could run unattended at night. Kiichiro Toyoda oversaw the building and start-up of a factory to produce the new looms, and set up 520 of them in the Toyoda experimental weaving factory. After he proudly showed off these "perfect looms," orders for the automated looms poured in. Kiichiro used the profits to start up an automotive business. He toured Detroit and spent years learning how to build engines. Toyota's first production car hit the market in 1936, but manufacturing was soon interrupted by war.

The Toyota Production System

Koromo, Japan, October 1949. Passenger car production restrictions were lifted in post-war Japan. In 1945, Kiichiro Toyoda had challenged his company to "catch up with America," but it was clear that Toyota could not catch up by adopting America's mass production model. Mass production meant making thousands of identical parts to gain economies of scale, but materials were scarce, orders were spotty, and variety was in demand. Economies of scale were simply not available.

Kiichiro Toyoda's vision was that all parts for assembly should arrive at the assembly line "Just-in-Time" for their use. This was not to be accomplished by warehousing parts; parts should be made just before they are needed. It took time to make this vision a reality, but in 1962, a decade after Kiichiro Toyoda's death, his company adopted the Toyota Production System companywide.

Taiichi Ohno

Taiichi Ohno was a machine shop manager who responded to Kiichiro Toyoda's challenge and vision by developing what came to be known as the Toyota Production System. He studied Ford's production system and gained insight from the way American supermarkets handled inventory. To this he added his knowledge of spinning and weaving and the insights of the workers he supervised. It took years of experimentation to gradually develop the Toyota Production System, a process that Ohno considered never-ending. He spread the ideas across the company as he was given increasingly broad areas of responsibility.

In his book, *Toyota Production System*, [2] Ohno calls the Toyota Production System "a system for the absolute elimination of waste." He explains that the system rests on two pillars: Just-in-Time flow and autonomation (also called Jidoka).

Just-in-Time Flow

It is important to note that Just-in-Time flow went completely against all conventional wisdom of the time. Resistance to Ohno's efforts was tremendous, and he succeeded because he was backed by Eiji Toyoda, who held various senior management positions in the company after his cousin Kiichiro left in 1950. Both Toyodas had brilliantly perceived that the game to be played was not economies of scale, but conquering complexity. Economies of scale will reduce costs about 15 percent to 25 percent per unit when volume doubles. But costs go up by 20 percent to 35 percent every time variety doubles.[3] Just-in-Time flow drives out major contributors to the cost of variety. In fact, it is the only industrial model we have that effectively manages complexity. [4]

Autonomation (Jidoka)

Toyoda automated looms could operate without weavers present because the looms detected when anything went wrong and shut down automatically. Autonomation, or its Japanese name Jidoka, means that work is organized so that the slightest abnormality is immediately detected, work stops, and the cause of the problem is remedied before work resumes. Another name for this critical concept, and one that is perhaps easier to remember, is "stop-the-line."

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2. This section is based on Taiichi Ohno's book, *Toyota Production System: Beyond Large-Scale Production*, Productivity Press, written in Japanese in 1978 and translated into English in 1988. It is an excellent book, very readable and highly recommended even today.
3. George Stalk, "Time—The Next Source of Competitive Advantage," *Harvard Business Review*, July 1988.
4. See "Lean or Six Sigma," by Freddy Balle and Michael Balle, available at www.lean.org/library/leanorsigma.pdf.

Ohno called autonomation "automation with a human touch." He pointed out how the related word "autonomic" brings to mind another way to look at this concept. Our bodies have an autonomic nervous system that governs reflexes such as breathing, heartbeat, and digestion. If we touch something hot, our autonomic nerves cause us to withdraw our hand without waiting for the brain to send a message. Autonomation means the organization has reflexes in place that will respond instantly and correctly to events without having to go to the brain for instructions.[5]

Shigeo Shingo

Shigeo Shingo was a consultant who helped Ohno implement the Toyota Production System at Toyota, and later helped companies around the world understand and implement the system. Those of us who implemented Just-in-Time manufacturing in the early '80s fondly remember the "Green Book,"[6] the first book on Just-in-Time published in English. It was not a good translation, and the material is heavy and technical, but it is a stunningly insightful book.

Shingo covers two major themes in the book: nonstock production and zero inspection. A careful look shows that these are actually the engineering equivalent of Ohno's pillars of the Toyota Production System.

Nonstock Production

Just-in-Time flow means eliminating the stockpiles of in-process inventory that used to be made in the name of economies of scale. The focus is on making everything in small batches, and in order to do this, it is necessary to be able to changeover a machine from making one part to making a different part very quickly. In software development, one way to look at set-up time is to consider the time it takes to deploy software. Some organizations take weeks and months to deploy new software, and because of this they put as many features into a release as possible. This gives them a large batch of testing, training, and integration work to do for each release. On the other hand, I expect the antivirus software on my computer to be updated with a well-tested release within hours after a new threat is discovered. The change will be small, so integration and training are generally not a concern.

Zero Inspection

The idea behind autonomation is that a system must be designed to be mistake-proof. There should not be someone looking for a machine to break or testing

5. Taiichi Ohno, Ibid., p. 46.
6. Shigeo Shingo, *Study of 'Toyota' Production System*, Productivity Press, 1981.

product to see if it is good. A properly mistake-proofed system will not need inspection. My video cable is an example of mistake-proofing. I can't plug a monitor cable into a computer or video projector upside down because the cable and plug are keyed. So I don't need someone to inspect that I plugged the cable in correctly, because it's impossible to get it wrong. Mistake-proofing assumes that any mistake that can be made will eventually be made, so take the time at the start to make the mistake impossible.

Just-in-Time

The Toyota Production System was largely ignored, even in Japan, until the oil crisis of 1973, because companies were growing quickly and they could sell everything they made. But the economic slowdown triggered by the oil crisis sorted out excellent companies from mediocre ones, and Toyota emerged from the crisis quickly. The Toyota Production System was studied by other Japanese companies and many of its features were adopted. Within a decade America and Europe began to feel serious competition from Japan. For example, I (Mary) was working in a video cassette plant in the early '80s when Japanese competitors entered the market with dramatically low pricing. Investigation showed that the Japanese companies were using a new approach called Just-in-Time, so my plant studied and adopted Just-in-Time to remain competitive.

The picture that we used at our plant to depict Just-in-Time manufacturing is shown in Figure 1.1.

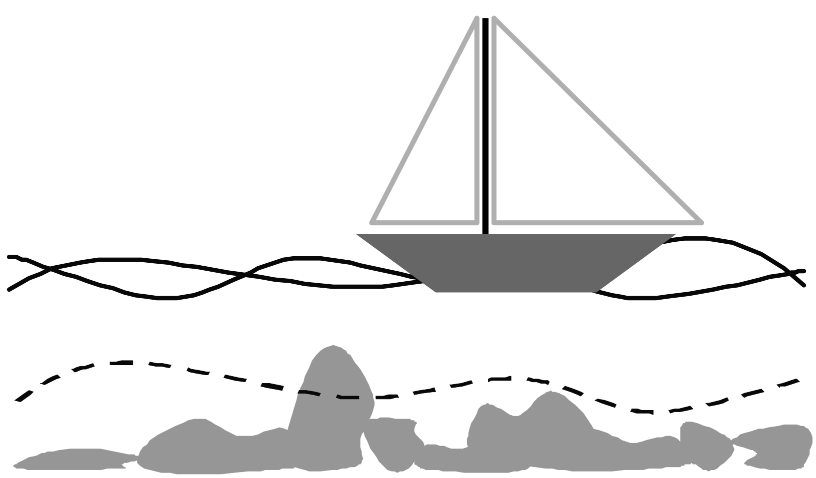

Figure 1.1 *Lower inventory to surface problems*

Inventory is the water level in a stream, and when the water level is high, a lot of big rocks lurking under the water are hidden. If you lower the water level, the big rocks begin to surface. At that point, you have to clear the rock out of the way, or your boat will crash into them. As the big rocks are removed, you can lower inventory level some more, find more rocks, clear them out of the stream, and keep on going until there are just pebbles left.

Why not just keep the inventory high and ignore the rocks? Well, the rocks are things like defects that creep into the product without being detected, processes that drift out of control, finished goods that people aren't going to buy before the shelf life expires, an inventory tracking system that keeps on losing track of inventory—things like that. The rocks are hidden waste that is costing you a lot of money—you just don't know it unless you lower the inventory level.

A key lesson from our Just-in-Time initiative was that we had to stop trying to maximize local efficiencies. We had a lot of expensive machines, so we thought we should run them each at maximum productivity. But that only increased our inventory, because a pile of inventory built up at the input to each machine to keep it running, and at the output from each machine as it merrily produced product that had nowhere to go. When we implemented Just-in-Time, the piles of inventory disappeared, and we were surprised to discover that the overall performance of the plant actually *increased* when we did not try to run our machines at maximum utilization (see Figure 1.2).

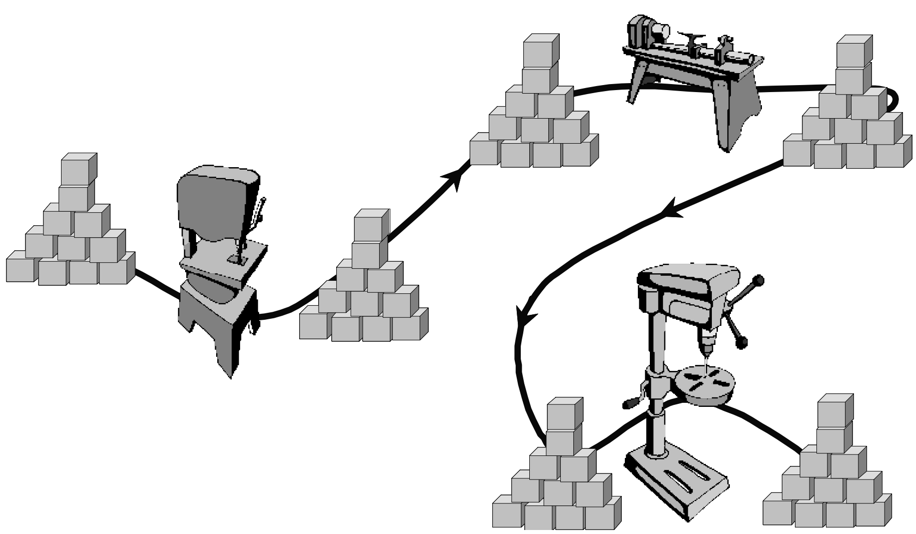

Figure 1.2 *Stop trying to maximize local efficiencies.*

Stop-the-Line and Safety Consciousness

One Just-in-Time practice that was easy to adopt was a stop-the-line culture. Our video tape plant made tape out of some rather volatile materials, so we had an aggressive safety program in place. Through our safety program we already knew that it was important to investigate even the smallest accident, because small accidents will eventually turn into big accidents if they are ignored.

The book *Managing the Unexpected*[7] by Weick and Sutcliffe shows that organizations like our plant create an environment where people pay attention to safety by maintaining a state of *mindfulness*. According to the authors, mindfulness has five characteristics:

1. **Preoccupation with Failure**
   We spent a lot of time thinking about what could go wrong and being prepared.
2. **Reluctance to Simplify**
   We had a large, complex plant, so safety was a large, complex issue.
3. **Sensitivity to Operations**
   Every manager in the plant was expected to spend time working on the line.
4. **Commitment to Learn from Mistakes**
   Even the smallest incident was investigated to determine how to prevent it from ever happening again.
5. **Deference to Expertise**
   Every manager knew that the people doing the work were the ones who *really* understood how the plant worked.

It was a small step to turn our safety culture into a stop-the-line culture. We added to our preoccupation with accidents a preoccupation with defects. Every step of every operation was mistake-proofed as we focused on eliminating the need for after-the-fact inspection. Whenever a defect occurred, the work team stopped producing product and looked for the root cause of the problem. If defective material made it through a process undetected, we studied the process to find out how to keep that from happening again. When I say "we" I refer to our production workers, because they were the ones who designed the process in the first place.

—Mary Poppendieck

7. Karl E. Weick and Kathleen M. Sutcliffe, *Managing the Unexpected: Assuring High Performance in an Age of Complexity*, Jossey-Bass, 2001.

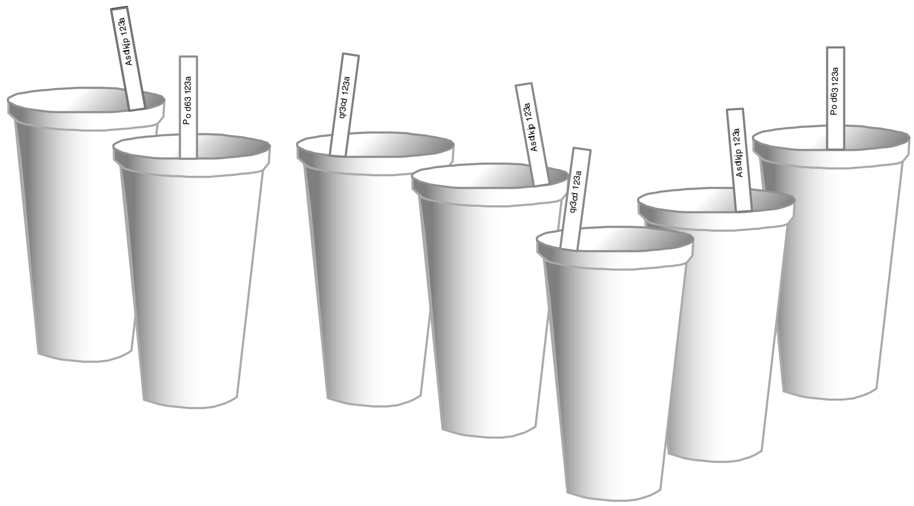

Figure 1.3 *Coffee cups simulating inventory carts with kanban cards*

When we decided to move our plant to Just-in-Time, there were few consultants around to tell us what to do, so we had to figure it out ourselves. We created a simulation by covering a huge conference table with a big sheet of brown paper, then drawing the plant processes on the paper. We made "kanban cards" by writing various inventory types on strips cut from index cards. We put an inventory strip into a coffee cup and—viola!—that cup became a cart full of the indicated inventory. (See Figure 1.3.) Then we printed a week's packing orders and simulated a pull system by attempting to fill the orders, using the cups and the big sheet of paper like a game board. When a cup of inventory was packed, the inventory strip (kanban card) was moved to the previous process, which used it as a signal to make more of that material.[8]

With this manual simulation we showed the concept of a pull system to the production managers, then the general supervisors, then the shift supervisors. Finally, the shift supervisors ran through the simulation with every worker in their area. Each work area was asked to figure out the details of how to make this new pull system work in their environment. It took some months of detailed preparation, but finally everything was ready. We held our collective breath as we changed the whole plant over to a pull system in one weekend. Computerized scheduling was turned off, its place taken by manual scheduling

8. This scheduling approach is called Kanban, and the token showing what each process should make is called a kanban card.

via kanban cards. Our Just-in-Time system was an immediate and smashing success, largely because the details were designed by the workers, who therefore knew how to iron out the small glitches and continually improve the process.

Lean

In 1990 the book *The Machine That Changed the World*[9] gave a new name to what had previously been called Just-in-Time or the Toyota Production System. From then on, Toyota's approach to manufacturing would become known as **Lean Production**. During the next few years, many companies attempted to adopt Lean Production, but it proved remarkably difficult. Like all new industrial models, resistance from those invested in the old model was fierce.

Many people found Lean counterintuitive and lacked a deep motivation to change long established habits. Quite often companies implemented only part of the system, perhaps trying Just-in-Time without its partner, stop-the-line. They missed the point that, "The truly lean plant…*transfers the maximum number of tasks and responsibilities to those workers actually adding value to the car on the line, and it has in place a system for detecting defects that quickly traces every problem, once discovered, to its ultimate source.*"[10]

Despite the challenges faced when implementing a counterintuitive new paradigm, many lean initiatives have been immensely successful, creating truly lean businesses, which have invariably flourished. Lean thinking has moved from manufacturing to other operational areas as diverse as order processing, retail sales, and aircraft maintenance. Lean principles have also been extended to the supply chain, to product development, and to software development. See Figure 1.4.

Lean Manufacturing/Lean Operations

Today lean manufacturing sets the standard for discipline, efficiency, and effectiveness. In fact, using lean principles in manufacturing often creates a significant competitive advantage that can be surprisingly difficult to copy. For example, Dell Computer's make-to-order system routinely delivers a "custom-built" computer in a few days, a feat which is not easily copied by competitors unwilling to give up their distribution systems. Lean has moved into nonmanufacturing operations as well. Southwest Airlines focuses on transporting custom-

9. James Womack, Daniel Jones, and Daniel Roos, *The Machine That Changed the World*, Rawson Associates, 1990.
10. Ibid., p. 99. Italics are from original text.

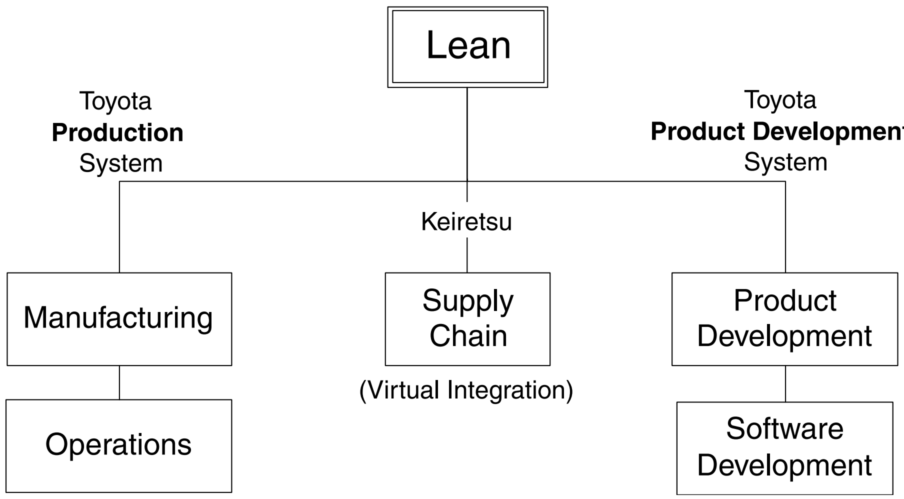

Figure 1.4 *The lean family tree*

ers directly from point A to point B in relatively small planes, while competitors can't easily abandon their large-batch oriented hub-and-spoke systems. A few industries, such as rapid package delivery, have been structured based on lean principles, and in those industries, only companies with lean operations can survive.

Lean Supply Chain

When lean production practices reach the plant walls, they have to be extended to suppliers, because mass production and lean manufacturing do not work well together. Toyota realized this early, and helped its suppliers adopt the Toyota Production System. Peter Drucker estimated that Toyota's supplier network, which Drucker calls a Keiretsu, gives it a 25 percent to 30 percent cost advantage relative to its peers.[11] When Toyota moved to the United States in the late 1980s, it established a similar supplier network. Remarkably, US automotive suppliers often have lean sections of their plants dedicated to supplying Toyota, while the rest of the plant has to be run the "traditional" way because other automotive companies cannot deal with a lean supplier.[12] A lean supply chain is

11. Peter Drucker, *Management Challenges for the 21st Century*, Harper Business, 2001, p. 33.
12. See Jeffrey Dyer, *Collaborative Advantage: Winning Through Extended Enterprise Supplier Networks*, Oxford University Press, 2000.

also essential to Dell, since it assembles parts designed and manufactured by other companies. Through "virtual integration," Dell treats its partners as if they are inside the company, exchanging information freely so that the entire supply chain can remain lean.

In lean supply chains, companies have learned how to work across company boundaries in a seamless manner, and individual companies understand that their best interests are aligned with the best interests of the entire supply chain. For organizations involved in developing software across company boundaries, supply chain management provides a well-tested model of how separate companies might formulate and administer lean contractual relationships.

Lean Product Development

"The real differential between Toyota and other vehicle manufacturers is not the Toyota Production System. It's the Toyota Product Development System," says Kosaku Yamada, chief engineer for the Lexus ES 300.[13] Product development is quite different than operations, and techniques that are successful in operations are often inappropriate for development work. Yet the landmark book *Product Development Performance*[14] by Clark and Fujimoto shows that effective product development has much in common with lean manufacturing. Table 1.1 summarizes the similarities described by Clark and Fujimoto.

If any company can extract the essence of the Toyota Production System and properly apply it to product development, Toyota would be the top candidate. So there was no surprise when it became apparent in the late 1990s that Toyota has a unique and highly successful approach to product development. Toyota's approach is both counterintuitive and insightful. There is little attempt to use the manufacturing-specific practices of the Toyota Production System in product development, but the underlying principles clearly come from the same heritage.

The product coming out of a development process can be brilliant or mundane. It might have an elegant design and hit the market exactly right, or it might fall short of both customer and revenue expectations. Toyota products tend to routinely fall in the first category. Observers attribute this to the leadership of a chief engineer, responsible for the business success of the product, who has both a keen grasp of what the market will value and the technical capability

13. Gary S. Vasilash, "Engaging the ES 300," *Automotive Design and Production*, September, 2001.
14. Kim B. Clark and Takahiro Fujimoto, *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry,* Harvard Business School Press, 1991.

Table 1.1 *Similarities between Lean Manufacturing and Effective Product Development*[15]

Lean Manufacturing	Lean Development
Frequent set-up changes	Frequent product changes (software releases)
Short manufacturing throughput time	Short development time
Reduced work-in-process inventory between manufacturing steps	Reduced information inventory between development steps
Frequent transfer of small batches of parts between manufacturing steps	Frequent transfer of preliminary information between development steps
Reduced inventory requires slack resources and more information flow between steps	Reduced development time requires slack resources and information flow between stages
Adaptability to changes in volume, product mix, and product design	Adaptability to changes in product design, schedule, and cost targets
Broad task assignments for production workers gives higher productivity	Broad task assignments for engineers (developers) gives higher productivity
Focus on quick problem solving and continuous process improvement	Focus on frequent incremental innovation and continuous product and process improvement
Simultaneous improvement in quality, delivery time, and manufacturing productivity	Simultaneous improvement in quality, development time, and development productivity

to oversee the systems design. In the book *The Toyota Way*,[16] Jeffrey Liker recounts the stories of the development of the Lexus and the Prius, emphasizing how these breakthrough designs were brought to market in record time under the leadership of two brilliant chief engineers.

Product development is a knowledge creation process. Toyota's Product Development System creates knowledge through broad exploration of design spaces, hands-on experimentation with multiple prototypes, and regular inte-

15. Adapted from Kim B. Clark and Takahiro Fujimoto, *Product Development Performance,* p. 172.
16. Jeffrey Liker, *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw Hill, 2004.

gration meetings at which the emerging design is evaluated and decisions are made based on as much detailed information as possible. The tacit knowledge gained during both development and production is condensed into concise and useful one-page summaries that effectively make the knowledge explicit. Generating and preserving knowledge for future use is *the* hallmark of the Toyota Product Development System.

The National Center for Manufacturing Sciences (NCMS) conducted a multi-year study of the Toyota Product Development System, and the findings are summarized by Michael Kennedy in the book *Product Development for the Lean Enterprise*.[17] In this book Kennedy identifies four cornerstone elements of the Toyota Product Development System (see Figure 1.5).

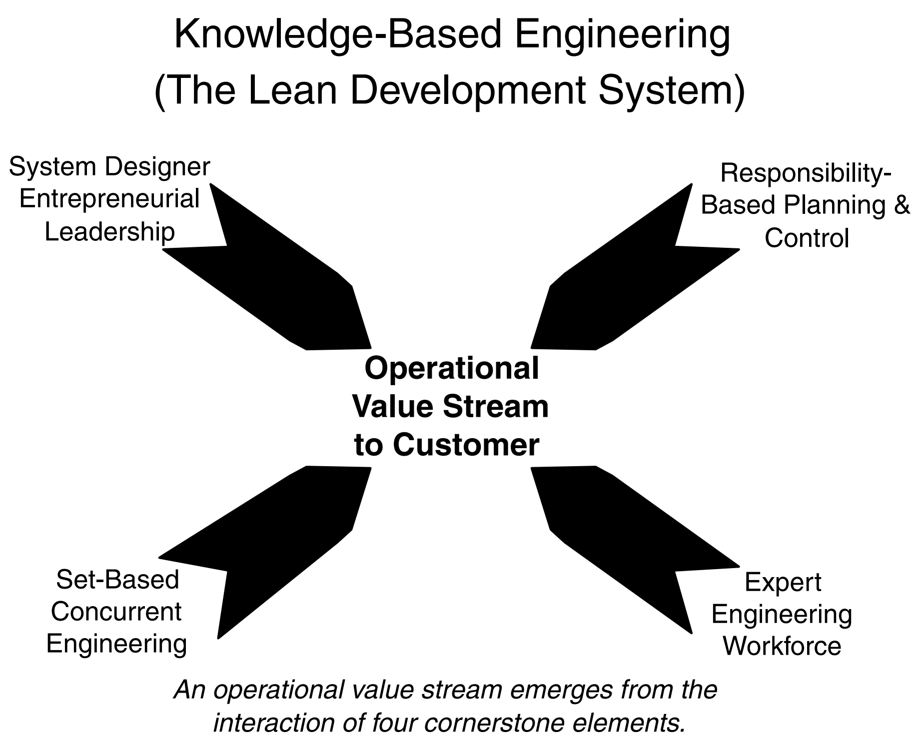

Figure 1.5 *Cornerstone elements of the Toyota Product Development System*[18]

17. Michael Kennedy, *Product Development for the Lean Enterprise: Why Toyota's System Is Four Times More Productive and How You Can Implement It*, Oaklea Press, 2003.
18. This figure is from Michael Kennedy, Ibid., p. 120. Used with permission.

The Toyota Product Development System

The Toyota Product Development System has four cornerstone elements:

1. **System Design by an Entrepreneurial Leader**
   The chief engineer at Toyota owns responsibility for the business success of the product. He is a very experienced engineer, fully capable of creating the system-level design of the vehicle. But he is also responsible for developing a deep understanding of the target market and creating a vehicle that will delight the customers. The chief engineer creates a vision of the new product which he transmits to the development team and refreshes frequently by talking to the engineers making day-to-day decisions. He defends the vision when necessary and arbitrates tradeoffs if disagreements arise. He sets the schedule and modifies the process so everything is pulled together on time.
2. **Expert Engineering Workforce**
   From the days of Sakichi Toyoda, the Toyoda and Toyota companies have always had top notch technical people designing their technically sophisticated products. It takes years for an engineer to really become an expert in a particular area, and at Toyota, engineers are not moved around or motivated to move into management before they truly master their field. Managers are teachers who have become masters in the area they supervise; they train new engineers and move them from apprentice to journeyman to master engineer.
3. **Responsibility-Based Planning and Control**
   The chief engineer sets the vehicle development schedule, which consists of key synchronization points about two or three months apart. Engineers know what is expected at the next synchronization point, and they deliver the expected results without being tracked. If engineers need information to do their job, they are expected to “pull” it from its source. Recently, Toyota chief engineers have pioneered the practice of an “Oobeya” or large room where team members may work, and the whole team meets regularly. The Oobeya contains big visible charts to show issues and status.
4. **Set-Based Concurrent Engineering**
   Set-based engineering means exploring multiple design spaces and converging on an optimal solution by gradually narrowing options. What does this mean in practice? It means being very careful not to make decisions until they absolutely must be made and working hard to maintain options so that decisions can be made as late as possible with the most amount of information possible. The paradox of set-based design is that this approach to creating knowledge builds redundancy into the development approach, which might appear to be a waste. However, when looking at the whole system, set-based design allows the development team to arrive at a more optimal solution much faster than an approach that closes off options quickly for the sake of being “decisive.”[19]

19. For more on set-based engineering, see Chapter 7.

Lean Software Development

Software development is a form of product development. In fact, much of the software you use was probably purchased as a product. Software that is not developed as a standalone product may be embedded in hardware, or it may be the essence of a game or a search capability. Some software, including much custom software, is developed as part of a business process. Customers don't buy the software we develop. They buy games or word processors or search capability or a hardware device or a business process. In this sense, most useful software is embedded in something larger than its code base.

It is the product, the activity, or the process in which software is embedded that is the real product under development. The software development is just a subset of the overall product development process. So in a very real sense, we can call software development a subset of product development. And thus, if we want to understand lean software development, we would do well to discover what constitutes excellent product development.

The Toyota Production System and the Toyota Product Development System stem from the same underlying principles. The first step in implementing lean software development is to understand these underlying principles, which will be discussed in the next chapter.

Try This

1. Go to the Toyota Web site, and view the video on Jidoka (www.toyota.co.jp/en/vision/production_system/video.html[20]). You will see sophisticated Toyoda automated looms from the 1920s. The videos on Just-in-Time and the Toyota Production System are also worth viewing.

2. Do you have a tendency to work in batches? If you had to mail 100 letters, how would you go about folding the letters, stuffing the envelopes, adding address labels and stamps? Would you process one envelope at a time, or would you perform each step in a batch? Why? Try timing both ways and see which is faster. If you have children, ask them how they would approach the problem.

20. This was a newly published Web site as of April, 2006. The page can also be reached by going to www.toyota.co.jp/en/ and following this sequence: Top Page > Company > Vision & Philosophy > Toyota Production System > Video Introducing the Toyota Production System.

3. Table 1.1 lists similarities between manufacturing and product development. Discuss this table with your team, one line at a time. Does it make sense in your world to think of partially done work as inventory? Do the other analogies make sense? Analogies are a double-edged sword. Where might the analogies between manufacturing and product development lead you astray?

4. Work-arounds: You have an organization of intelligent people. Do these people make it their job to work around problems, or are problems considered a trigger to stop-the-line and find the root cause? Make a list of the Top 10 problems that occurred in your group in the last week. List after each problem the way it was resolved. Rank each problem on a scale of 0–5. The rank of 5 means that you are confident that the cause of the problem has been identified and eliminated and it is unlikely to occur again. The rank of 0 means that there is no doubt the problem will crop up again. What is your total score?

5. If people in your organization instinctively work around problems, they have the *wrong reflexes*! Brainstorm what it will take to develop a culture that does not tolerate abnormalities, whether it is a broken build or a miscommunication, a failed installation or code that is not robust enough to hold up in production. Have a “stop-the-line” committee investigate the ideas and choose the best candidate to get started. In the one chosen area, switch from a work-around culture to a stop-the-line culture. Be sure reflexive stop-the-line habits are developed! Repeat.