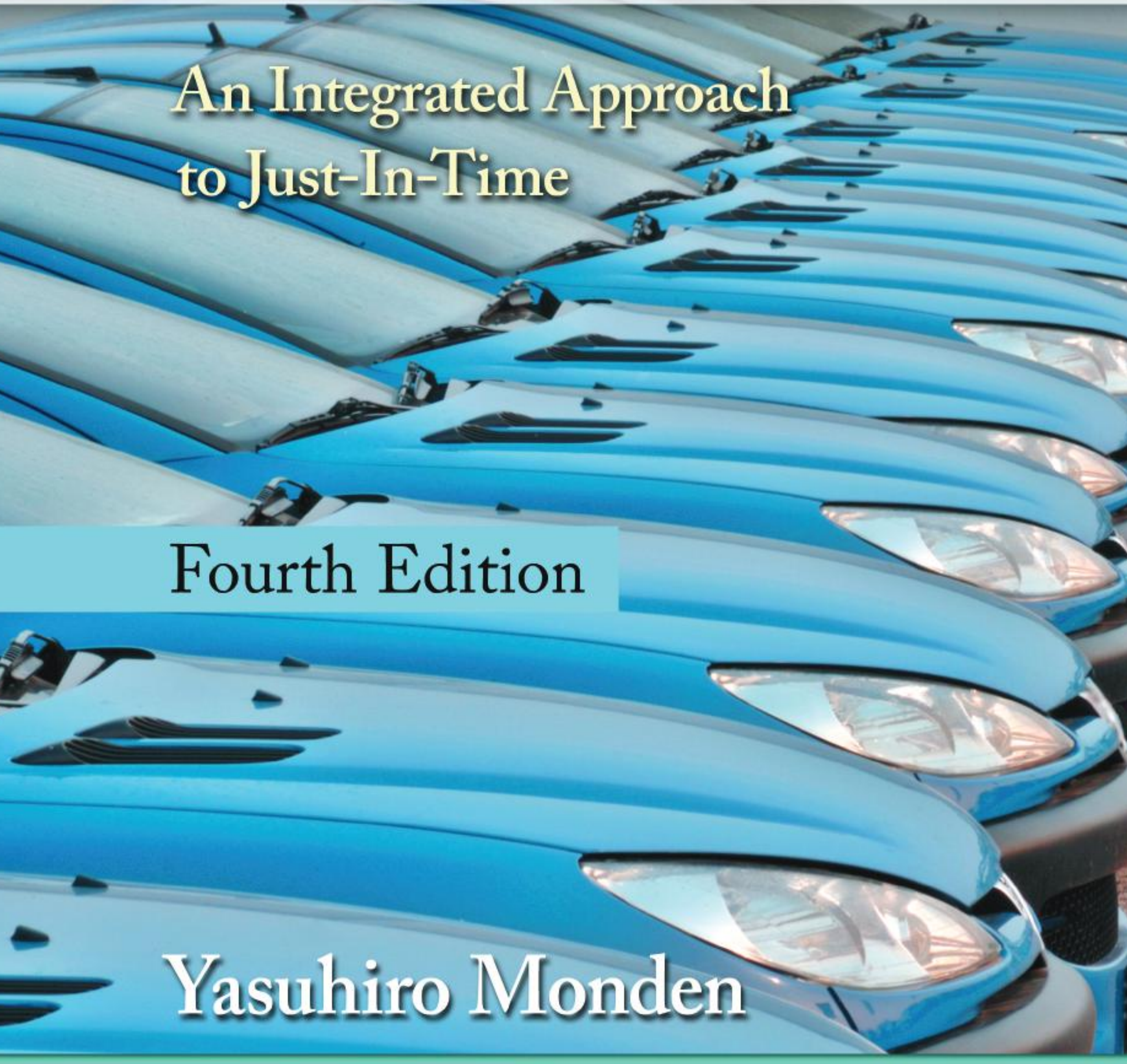
TOYOTA Production System

An Integrated Approach to Just-In-Time



Fourth Edition

Yasuhiro Monden

Institute of Industrial Engineers

CRC Press
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A PRODUCTIVITY PRESS BOOK

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Foreword to the First Edition

The technique we call the Toyota production system was born through our various efforts to catch up with the automotive industries of western advanced nations after the end of World War II, without the benefit of funds or splendid facilities.

Above all, one of our most important purposes was increased productivity and reduced costs. To achieve this purpose, we put our emphasis on the notion of eliminating all kinds of unnecessary functions in the factories. Our approach has been to investigate one by one the causes of various "unnecessaries" in manufacturing operations and to devise methods for their solution, often by trial and error.

The technique of kanban as a means of just-in-time production, the idea and method of production smoothing, autonomation (jidoka), and so on, have all been created from such trial-and-error processes in the manufacturing sites.

Thus, since the Toyota production system has been created from actual practices in the factories of Toyota, it has a strong feature of emphasizing practical effects, and actual practice and implementation over theoretical analysis. As a result, it was our observation that even in Japan it was difficult for the people of outside companies to understand our system; still less was it possible for the foreign people to understand it.

This time, however, Professor Monden wrote this book by making good use of his research and teaching experiences in the United States. Therefore, we are very interested in how Professor Monden has "theorized" our practice from his academic standpoint and how he has explained it to the foreign people. At the same time, we wish to read and study this book for our own future progress.

At no other time in history has the problem of productivity received so much discussion. No longer is it solely an economic problem; now it presents a serious political problem in a form of trade frictions. At such a time it would be our great pleasure if the Toyota production system we invented could be of service to the problem of American productivity.

Although we have a slight doubt whether our just-in-time system could be applied to the foreign countries where the business climates, industrial relations, and many other social systems are different from ours, we firmly believe there is no significant difference among the final purposes of the firms and people working in them.

Therefore, we hope and expect that another effective American production system will be created utilizing this book for reference.

Taiichi Ohno
Former Vice President, Toyota Motor Corporation
Former President, Japan Industrial Management Association
Former Chairman, Toyoda Spinning and Weaving Co., Ltd.

Preface to the Fourth Edition

§ 1 THE BASIC PHILOSOPHY OF THE TOYOTA PRODUCTION SYSTEM: CONTINUOUS IMPROVEMENT

It seems most appropriate to launch this fourth edition of *Toyota Production System* by reviewing Toyota's recent quality and excess inventory problems and considering the questions: Why did these problems occur? Did the Toyota Production System (TPS) work well or not? What will be the future of Toyota?" A brief analysis will help lay the groundwork for this new edition and emphasize the true effectiveness of the authentic Toyota Production System.

On February 24, 2010, Mr. Akio Toyoda, President of Toyota Motors, testified in hearings held by the U.S. House of Representatives Committee on Oversight and Government Reform regarding safety issues with Toyota's automobiles, as follows:

"First, I want to discuss the philosophy of Toyota's quality control. I myself, as well as Toyota, am not perfect. At times, we do find defects. But in such situations, we always stop, strive to understand the problem, and make changes to improve further. In the name of the company, its long-standing tradition and pride, we never run away from our problems or pretend we don't notice them. By making continuous improvements, we aim to continue offering even better products for society. That is the core value we have kept closest to our hearts since the founding days of the company.

"At Toyota, we believe the key to making quality products is to develop quality people. Each employee thinks about what he or she should do, continuously making improvements, and by doing so, makes even better cars." (Toyoda, 2010)

As I see it, this explains the basic idea of "*continuous improvement*" in the Toyota Production System, and in Toyota's quality assurance activities.

§ 2 TOYOTA'S QUALITY PROBLEMS AND THEIR COUNTERMEASURES

The Reasons for Quality Problems and Successive Recalls of Toyota Cars

Delay of Human Resource Development because of Rapid Growth in Volumes

Toyota car recalls that were subject to special public scrutiny occurred successively from the end of 2009 into 2010. As just two examples: (1) On November 25, 2009, Toyota recalled more than eight million cars globally to fix floor mats and sticky accelerators: the floor mats can trap accelerators to the floor and the "sticky" accelerator pedals don't return to idle. Toyota identified these defects. (2) On February 8, 2010, Toyota announced a recall of more than 100,000 vehicles to update the anti-lock braking system (ABS) software, in response to problems reported in hybrid cars.

President Akio Toyoda explained the reasons for these quality problems in his testimony at the committee hearing cited above, as follows:

"I would like to discuss what caused the recall issues we are facing now. Toyota has, for the past few years, been expanding its business rapidly. Quite frankly, I fear the pace at which we have grown may have been too quick. I would like to point out here that Toyota's priority has traditionally been the following: First; Safety, Second; Quality, and Third; Volume. These priorities became confused, and we were not able to stop, think, and make improvements as much as we were able to before, and our basic stance to listen to customers' voices to make better products has weakened somewhat. We pursued growth over the speed at which we were able to develop our people and our organization." (Toyoda, 2010)

Since Toyota exceeded its annual production volume of 6 million cars in 2002, production and sales volumes have continuously expanded at the pace of 500,000 vehicles per year. Such tremendously quick growth has resulted in insufficient time for developing quality people. By selling 8,972,000 cars in 2008, Toyota earned the position of the world's number one carmaker, surpassing GM. In 2010, Toyota achieved production capacity of 10 million cars. Such an enthusiastic pursuit of volume itself was not sound. Mr. Toyoda's testimony that Toyota "pursued growth over the speed at which we were able to develop our people and our organization" is based on this reflection.

Recent Difficult Problems in Quality Management of Automobiles

Many components that support various functions in current-model cars are electronically controlled, and the software is developed simultaneously with the electronic parts. Such simultaneous development of electronic hardware and software makes it difficult to track down problems in electronic control systems. Most troubles are caused by mistakes in the design phase rather than in manufacturing. The above-mentioned recall of hybrids because of problems with the ABS system is one example.

In the design process of an automobile, assuring the quality of a group of parts configured with many complicated technical constraints must entail the optimal simultaneous development of both electronic control systems and their software. For such difficult problems, not only Toyota but all automakers must develop innovative solutions.

Opposing Opinions of Toyota and the U.S. Department of Transportation Regarding Suspect Quality of Computer-Controlled Throttle Systems

Although Toyota identified defects related to floor mats that can trap accelerators and "sticky" accelerator pedals that don't return to idle, Toyota's position is that reported incidents of sudden-acceleration involving its vehicles weren't caused by defects in electronic throttle control (ETC) systems. On February 12, 2010, Toyota submitted to the Committee the research report of a third-party U.S. consulting organization, Exponent, Inc.; their report supported the quality of Toyota's ETC.

To further investigate this controversial matter, the National Highway Traffic Safety Administration (NHTSA) of the U.S. Department of Transportation analyzed 58 cases of data from the event data recorder (EDR) of Toyota vehicles involved in accidents blamed on "unintentional" sudden acceleration and found that the throttles were wide open and the brakes were not engaged at the time of crash (*The Wall Street Journal,* WSJ.com, 2010).

On August 10, 2010, the U.S. Department of Transportation formally reported to the House of Representatives that there were no findings of any problems in Toyota's ETC. In 38 of the 58 cases blamed on "unintentional" sudden acceleration, the brakes were never engaged at all, and in 9 cases the brakes were engaged immediately before the crashes, suggesting driver error.

Toyota's Countermeasures for Future Quality Assurance

In his last statements at the Committee hearing, Akio Toyoda explained his policy on countermeasures for future quality assurance at Toyota, as follows:

> I would like to discuss how we plan to manage quality control as we go forward. [1] Up to now, any decisions on conducting recalls have been made by the Customer Quality Engineering Division at Toyota Motor Corporation in Japan. This division confirms whether there are technical problems and makes a decision on the necessity of a recall. However, reflecting on the issues today, what we lacked was the customers' perspective. [2] To make improvements on this, we will make the following changes to the recall decision-making process. When recall decisions are made, a step will be added in the process to ensure that management will make a responsible decision from the perspective of "customer safety first." [3] To do that, we will devise a system in which customers' voices around the world will reach our management in a timely manner, and also a system in which each region will be able to make decisions as necessary. (Toyoda, 2010, numbering of important phrases added)

As I see it, the emphasis in this statement is on the phrase *"the customers' perspective."*

§ 3 TOYOTA'S INVENTORY PROBLEM AND THE JIT PRODUCTION SYSTEM: WHY DID TOYOTA PILE UP DEALER INVENTORY OF MORE THAN 100 DAYS' SALES?

Japanese automakers were said to be averaging about 30 to 40 days of inventory in the United States when sales were good. Meanwhile, the "Big Three" U.S. automakers were reported to have had about 100 to 120 days of inventory in their dealerships and car-lease companies (Shimokawa, 2009, p. 50). The Big Three covered the dealers' burden by supplying incentives (sales bonuses or subsidies) and rebates (cash back or discounts). By carrying higher inventory in their dealerships, they managed to prop up the capacity usage rate of their plants.

Even Toyota, Honda, and Nissan, however, have had inventories of more than 100 days of sales in their dealerships after September 2008. Thanks to immediate reductions in production volume, they reduced their inventories to 60 days around March 2009. But it should be noted that they had formidable *excess* inventory for a certain period of time.

One of the reasons for this high inventory level is the rapid fall-off in car sales at that time, for example, the 35% reduction in October 2008 compared to the previous year, and the 37% decrease in November. Because of this dramatic decrease in demand, their existing inventory sharply increased in terms of inventory carrying days, even though they shut down many plants.

However, this is not the only reason for their excess inventory. Actually, Toyota's auto loan sales company showed a *deficit* at the end of March 2008, although it had been earning a big profit from financing revenues for several years prior (Shimokawa, 2009, p. 52). Therefore, it is obvious that Toyota's management failed to make a timely decision to reduce car production, neglecting to adjust to the reality that sales were slowing down in the United States.

In principle, the Toyota Production System (TPS) uses the rule of "producing salable items, at a salable point in time, in a salable quantity," which is the just-in-time (JIT) concept. Why did Toyota plants, then, continue to produce and deliver cars to dealers notwithstanding the real sales slowdown evident at the dealers? Although the TPS order-entry system is based on estimates provided by car dealers, the dealers send orders to Toyota in three tiers: the monthly order, ten-day order, and daily changed order. Using this three-tiered order-entry system, Toyota could have built cars to meet the nearest-term orders, which might be called a *quasi* build-to-order system. But did they actually follow their own TPS rule rigidly?

As stated above, the high-growth period in their market, which lasted for ten years before the sudden slowdown, allowed the belief that any volume produced could be sold. Top management at Toyota must have continued to decide on a manufacturer-driven policy for car deliveries to dealerships, which the dealers in turn accepted without saying, "No!"

As a matter of fact, the chairman of the board, Mr. Fujio Cho, admitted recently that, in a situation of continuous growth, people in the production and sales departments have become much too friendly with each other. In the past, the production people would say, "We produced because you asked us to sell," and the sales people would say, "We cannot sell what cannot be sold." Both parties spoke frankly without any compromise, so that excess production could be prevented (Cho, 2010). In other words, the rigorous mutual rules or disciplines of TPS were loosened during this period of volume growth.

Toyota's motivation for achieving the position of the number one car company in the world originated in the "global master plan" prepared in 2002, which showed their mid- and long-term product development and sales and production plans. This master plan was based on their "global vision for 2010," and it essentially determined future plant construction and human resource allocation worldwide, driving toward the goal of attaining a production capacity of 10 million cars.

In the past, Taiichi Ohno (founder of TPS) had been very careful and reluctant to construct plants, even in the post-war age of high economic growth. Since an automobile company requires massive facilities, there is always the threat that cash will not flow from their facilities when capacity-usage rates decline and plants lay idle. That is why TPS was developed as a system to supply merchandise in response to orders from dealerships, which would be as close as possible to actual market demand.

I firmly believe that the people on the manufacturing floor have been operating according to the rules of TPS. However, top management seems to have forgotten the basic concept of "just-in-time," erroneously thinking that the capacity-usage rate would never fall—an illusion which also resulted in the plan for building the capacity to manufacture 10 million cars in 2010.

§ 4 NOW IS THE CHANCE FOR TPS TO DISPLAY THE REAL VALUE OF CONTINUOUS IMPROVEMENT

In 1998, the global volume of Toyota's sales was 4,640,000 cars, but as mentioned previously, by 2008 that had almost doubled. That is why Toyota's management intensively and enthusiastically introduced mass production and speedy facilities.

Ohno's Approach

However, this attitude and thinking is entirely different from the concept of TPS taught by Taiichi Ohno. Ohno's TPS concept, even in previous periods of high growth, is different from that of Toyota's top management in recent years.

Ohno said,

> …[D]uring the 15-year period beginning in 1959-60, Japan experienced unusually rapid economic growth. As a result, mass production, American style, was still used effectively in many areas.
>
> We kept reminding ourselves, however, that careless imitation of the American system could be dangerous. Making many models in small numbers cheaply—wasn't this something we could develop? (Ohno, 1988, p. 1)

I have also emphasized Ohno's point at the end of Chapter 1 of every edition of this book:

> Where have these basic ideas come from? … They are believed to have come from the market constraints which characterized the Japanese automobile industry in post-war days—great variety within small quantities of production. Toyota thought consistently, from about 1950, that it would be dangerous to blindly imitate the Ford system (which minimized the averaged unit cost by producing in large quantities). American techniques of mass production have been good enough in the age of high-grade growth, which lasted until 1973 [the oil crisis]. In the age of low-level growth after the oil shock, however, the Toyota production system was given more attention and adopted by many industries in Japan in order to increase profit by decreasing costs or cutting waste.
>
> Mr. Ohno, throughout his entire tenure after World War II, cultivated people with the attitude that "Toyota has no money, no space and no human resources. Thus, why don't you display your ideas?" The manner in which he advised the Kyoto plant of Daihatsu Motors when introducing TPS in 1973 is described in Chapter 25 (one of the new chapters in this edition). Although it is not strange that most of Toyota's assembly lines are mixed-model lines where three or four different models (not just model variants) are flowing at the same time, the people in the production engineering department at Daihatsu totally rejected making such a mixed-model line at first. However, Ohno's strong instruction was that without investing any funds (i.e., without establishing a new plant), within limited space (i.e., using the lines of the existing plant), and without increasing the workforce, the new car model (called the "Starlet") had to be introduced to the line that was then assembling the "Publica" model. Daihatsu's Kyoto plant had no storage space for the new parts required for the "Starlet." Nevertheless, Ohno did not permit them to construct a new building, because that would add to the incremental fixed costs and thus jeopardize achieving the planned target cost of the Starlet. Everybody at Daihatsu was distressed and troubled, but they could

> not ignore the directions of the vice president of Toyota. On the other hand, Ohno also said, "People can provide good ideas when troubled." The people in the plant came up with many ideas and executed them until they worked well. For example, people in the stamping process decreased the lot size by half, from 12 shifts' worth of parts down to 6 shifts' worth, so that the necessary space could be created. This was just one of many ideas.

It is desirable for people to develop their capabilities through dealing with tougher processes, but because of the long-term boom in recent years at Toyota, employees cannot have had such good experiences. Yet, it was at the onset of just such a period of high-speed growth in the Japanese economy in 1962 that Ohno introduced the "kanban system" to all Toyota's plants; and the high growth rate lasted until the oil shock in 1973. During these 12 years of high growth, Ohno was consistently opposed to the *blind* introduction of massive production facilities.

The drawback of automated machines and facilities was their inability to stop when trouble happened; hence the workforce could not be reduced even though the plants were automated. Notwithstanding that reality, top management rushed to introduce automated equipment. As a result, Ohno developed the "jidoka" (autonomous defect control) system and avoided the blind introduction of mass production machines.

When production was cut back during the oil crisis, the problem of the "Te-i-in-se-i" (quorum system) became explicit. Except for completely unmanned machines, each automatic machine was always operated by two operators at the material input and output points, irrespective of whether the machine usage was at full or reduced capacity. In order to avoid such "Te-i-in-se-i," Ohno developed the "shojinka" (flexible workforce) system, which consists of U-form line layout, multi-skilled workers, and a system for the automatic stoppage of machines at each machine cycle.

Concluding Remarks for Moving Forward

As I see it, in this age of global recession, we can cultivate people based on the original idea of Ohno's system. Ohno also believed that TPS could serve as wisdom for surviving in an age of *low* economic growth.

When demand is reduced, the sales department will never confuse even though the production lines are stopped frequently because the sales people know that continuous production will just create excess inventory. Thus just "promote rationalization (or improvement) for the waste cut completely," "put back the original TPS rules," and "reduce the waste of human potential (through 'shojinka', or a flexible workforce)." Even though results will not flow easily to the bottom line, such accumulations of improvements (kaizen) can bring profits immediately in the next boom. Toyota's history is a repetition of such positive cycles.

Even when shojinka is promoted through various rationalizations, employees should not be laid off. (Too many temporary or non-regular employees will weaken the human resource capability. Japanese companies found out during the current recession that they should hire regular rather than non-regular employees.) On the other hand, cuts in overtime and the introduction of holidays without pay can be used to promote a kind of *work-sharing* so that labor cost cuts and stable employment are simultaneously achieved. As a result, even though an excess workforce may exist, the rationalization of plants can still be promoted and the fruits harvested quickly when a boom returns.

Another strength of TPS lies in the fact that it is a system of supply chain management in the industry as a whole. Inter-firm coalitions are well-executed in Japanese industries. These inter-firm networks work well in the product development phase as well as in manufacturing. The Toyota Production System is equivalent to the management system of inter-firm relations.

For example, automakers ask for collaboration with steel and iron producers, starting at the initial stage of product development. Thus, steel suppliers can provide new types of sheet metal that fit the new car models. Such well-managed alliances between auto manufacturers and all of the major component suppliers are a strength of Japanese industries.

The development lead time for an automobile is about two years, and the life cycle of the car in the market four years. Therefore, unless there is a long-term, stable relationship of mutual trust, inter-firm alliances are impossible. Toyota seems to take great care of such inter-firm networks in their supply chain rather than forming global alliances with other auto manufacturers.

In summary, it is best in this global age of recession that we make changes in ourselves based on the mindset of continuous improvement, without forgetting the priority of multiple goals: first, safety; second, quality; and third, volume. The importance of the *integrity of multiple goals in pursuing just-in-time* has been expressed in the subtitle of this book since its second edition.

Keeping in mind that TPS is a system of supply chain management, we should carefully cultivate inter-firm networks, or mutual trust in human relations. Managing in this way can offset the drawbacks of market mechanisms and work as a "*Visible Hand*" to coordinate supply and demand balances along the whole supply chain, and further to allow profit sharing (through *incentive prices*) for attaining win-win relationships among participating firms (for details see Monden, 1987/88 and 2011).

Finally, I firmly believe that Toyota will revive more quickly in their safety, quality, and sales volume performance if they try their best to return to their long-standing tradition of the TPS improvement philosophy.

§ 5 NEW CONTENTS IN THE FOURTH EDITION OF *TOYOTA PRODUCTION SYSTEM*

PART 1 Total System and Implementation Steps

Chapter 1: Additional Section, "The Goal of TPS"

In this fourth edition, minor additions have been made to most of the chapters, but Chapter 1 includes a longer new section entitled "The Goal of TPS." In this section, the goals of TPS are explained in terms of their effects not only on cost reduction, but also on cash flow increase as a result of inventory reduction.

In particular, I suggest that in order to enhance cash inflows throughout the supply chain as a whole, the core parent company of the consolidated business group should try to improve the performance measure of "*JIT cash flows*" by using a consolidated cash flow statement covering the entire supply chain.

Other additions to the fourth edition include the following eight chapters, which are entirely new:

PART 2 *Subsystems*

Chapter 9: One-Piece Production in Practice

Chapter 15: Kaizen Costing

Chapter 16: Material Handling in an Assembly Plant

Chapter 18: Smoothing Kanban Collection

TPS enables *one-piece* production that allows products to be made fluidly, one unit at a time, just as water flows through a river. Previous editions have not sufficiently described this important point, which is elaborated in Chapter 9 of this edition.

Chapter 15 explains *kaizen costing*, which is performed together with the application of TPS. Kaizen costing is one of the three cost management techniques that comprise target costing in the product development phase, and kaizen costing and standard costing in the manufacturing phases.

Chapter 16 introduces the handling of parts and materials at the assembly line side at Toyota, a practice that has been developed more recently.

Chapter 18 shows how supplier kanban can be collected in an *even* quantity at the line side in a plant and also collected *evenly* by suppliers. The kanban collection times within the plants and at the gates of Toyota's parts storage areas must be smoothed out, or handled in a regular rhythm. Various specific concepts and devices are used to satisfy this requirement.

PART 3 Quantitative Techniques

Chapter 22: Determination of the Number of Kanban

Chapter 23: New Developments in e-Kanban

Determination of the number of kanban has been one of my key research topics since publication of the first edition of *Toyota Production System* in 1983. The newly written Chapter 22 provides my most complete explanation of the kanban number calculation, and is the most elaborate chapter in the fourth edition.

Chapter 23 explains the mechanism and uses of the "electronic kanban," or e-kanban, which has been remarkably well developed and broadly utilized at the Toyota group in recent years. As Toyota has expanded its global production, it has increasingly outsourced both domestic and overseas EMS (electronic manufacturing services, which are OEM producers of electronics and electronic apparatus). For instance, the "sticky" accelerator pedals that don't return to idle in the Corolla and Camry models, which are the mainstay cars of Toyota, were manufactured by an American EMS, CTC. As their parts procurement net has expanded to broader regions, it has become tougher for Toyota to withdraw parts in a timely manner using their traditional type of supplier kanban. To cope with this geographical expansion of their parts network, Toyota developed and began to widely use the electronic kanban. This chapter introduces one of the most recent developments covered in this fourth edition.

Chapters 23 and 24 focus on very technical aspects of TPS; this is especially true of Chapter 24, which explains IT utilization in Toyota's current global supply chain. I recommend that readers also study the additional information provided in Chapter 6, on the new Toyota Network System, which also covers the usage of IT for global parts procurement.

PART 4 Humanized Production Systems

Chapter 25: Cultivating the Spontaneous Kaizen Mind

Chapter 29: Mini Profit Centers and the JIT System

Another characteristic of this fourth edition is the extension of the humanized production system aspect that was first introduced in the third edition. Although many companies have been implementing the tools and techniques of TPS, they have not had much success in embedding the philosophy or culture of TPS into their organizations. Chapter 25 develops the theme of "cultivating the spontaneous kaizen mind" in order to establish TPS holistically in a company.

The "mini profit center," as explained in Chapter 29, is a profit center team comprising about ten members, situated in a plant or administrative department. Creating these very small decentralized units provides incentives to improve costs and quality by implementing TPS in a manner motivated by profit consciousness. This is another new practice of TPS that focuses on human motivation.

APPENDIX: Reinforcing the JIT System after the Disasters of 3/11/2011, Japan

Finally, an appendix was quickly introduced to investigate how we could reinforce the JIT system for the whole supply-chain not to stop its flow under sudden stoppage of partial locations in the chain. I strongly recommended the inter-network of supply chains here.

TPS has evolved continuously as social and economic environments have changed. Now that I have completed the manuscript for this fourth edition, I wish to further challenge TPS to harmonize with environmental challenges, and look forward to writing about that in the fifth edition. Toward this goal, let us go forward step by step.

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Professor-Emeritus of Tsukuba University
Visiting Professor NUCB, Global MBA

Preface to the Third Edition

Any management system in the real world is an output of the development of its initial features over time. In other words, a management system undergoes the process of evolution.

Evolution implies the structural changes of a system to adapt to changes in the economic, technological, or social environments. The process of a system's evolution is a cumulative development process, where both *historical continuity* (inheriting the past elements) and *historical discontinuity* (adaptation to new conditions) exist at the same time (Urabe 1984).

The Toyota Production System always has both perpetual aspects and entirely new aspects. Mr. Taiichi Ohno, founder of this system, once told me that "'Toyota production system has to 'evolve' constantly to cope with severe competition in the global marketplace." Further, he said, "we have to improve the bottom line (operational profit) of the income statement by considering 'all aspects' of the company and make a continuous 'evolution' of Toyota production system." "All aspects" refers not only to problems directly related to manufacturing, but also those related to various indirect departments including production engineering, product development, and managerial offices (Ohno and Monden 1983).

Toyota's management, an integral part of its production system, exercises managerial and strategic decision capabilities as the driving force for the advancement of the system.

Through the display of *management* decision ability, the system is continuously improved to achieve better performance, while being maintained at the improved level. A new system evolves based on inherent strategic decision abilities and by taking into consideration all aspects of the company. The system evolves in response to changes in economic, technological, and social conditions by considering the problems of all the company's departments. Thus, the whole process of maintenance, improvement, and evolution forms a spiral chain to make the system continuously competitive.

In the first edition of this book (1983), I explained how the rationale (goals-means or causes-effects relationships) of the Toyota production system was developed over a period of 30 years.

In the second edition (1993), I added elements relating to computer technologies that enhance conventional just-in-time system performance. I discussed computer manufacturing technology (including an assembly line control system and an expert system for sequence scheduling), as well as a strategic information system. These evolved during the 1980s at Toyota.

In this third edition of *Toyota Production System,* I explain the system's recent evolution; specifically, pursuing the goal of respect for humanity. In other words, Toyota has developed an approach to boost morale in the assembly plant by (1) redesigning the assembly line into many split-lines and (2) improving working conditions by introducing ergonomic devices to alleviate fatigue.

Toyota promotes these improvements to forestall labor shortages in its plants. The supply of young Japanese labor is expected to decrease because of the following:

1. As of mid-1990, the population of 18-year-olds was 2 million, but is expected to decrease to 1.2 million (a 40% reduction) by the year 2010.
2. Japanese youngsters are inclined to dislike working in workshops. Most tasks are characterized as difficult, dirty, and dangerous *(3D)* (referred to in Japanese as *3K (Kitsui, Kitanai, and Kiken).*
3. International requirements have reduced Japan's labor hours to an average of 1800 per year.

With the above prospective phenomena in mind, Toyota's management identified that the labor shortage would be a very serious problem. Efforts were focused on the design of an attractive workshop and the introduction of an employee satisfaction scheme in the manufacturing site to attract an assembly line workforce of younger men, older people, and females.

In this edition, the reader can see how Toyota management has made its strategic decisions. Strategic decisions or evolution relies on top management's ability to find the gap between the target and actual performances and to take positive actions to bridge the gap (or solve the problem). In the 1980s, it was thought that introducing new computer technology into the plants would enhance productivity. In the early 1990s, Toyota management found that employee satisfaction or respect for humanity in the plants would be another important issue. Toyota's management is adhering to continuous improvement—the eternal concept of just-in-time—while making necessary judgments to enhance overall performance.

In this edition, I have added information on split-line systems (Chapter 24); ergonomic improvements (Chapter 25); TVAL, which is a formula for measuring fatigue rate (Appendix 2); and a multi-criterion scheduling system (Appendix 4). In relation to the concepts on smoothed production described in Chapter 4, Appendix 4, co-authored with Henry Aigbedo, presents four main concepts of production smoothing within the framework of sequencing the mixed model on the assembly line.

I hope this third edition will be like its predecessors—useful to the practical and academic worlds of production and operations management.

Yasuhiro Monden
Professor, Ph.D.
University of Tsukuba
Institute of Policy and Planning Sciences

Preface to the Second Edition

The just-in-time (JIT) manufacturing system is an eternal system in use by its founder, Toyota Motor Corporation, but it has taken on a new look.

Toyota Production System, Second Edition systematically describes the changes that have occurred to the most efficient production system in use today. Since the publication of the first edition of this book in 1983, Toyota has integrated JIT with computer-integrated manufacturing technology and a strategic information system.

The JIT goal of producing the necessary items in the necessary quantity at the necessary time is an eternal driver of production and operations management. The addition of computer-integrated technology (including expert systems by artificial intelligence) and information systems technology serves to further reduce costs, increase quality, and improve lead time. The new Toyota production system considers how to adapt production schedules to the demand changes in the marketplace while satisfying the goals of low cost, high quality, and timely delivery.

The first edition of this book, *Toyota Production System*, published in 1983, is the basis for this book. It was translated into many languages including Spanish, Russian, Italian, Japanese, and so on, and has played a definite role in inspiring production management systems throughout the world.

In parallel with the distribution of the first edition of this book, the Toyota production system (also known as just-in-time) has been applied throughout the world. This is evidence that the JIT concept within the Toyota production system is applicable to any country regardless of location, economic, and civil development. Additionally, this production system can be utilized in any size company in any industry.

Although this book is based on my previous work, *Toyota Production System*, it was written as an entirely new book. Nine chapters have been added, and chapters from the first edition have been revised or enlarged. Written for practitioners and researchers alike, this new book will provide a balanced and broad approach to the Japanese production system.

The major differences between the Toyota Production System of a decade ago and the current system are twofold: (1) computer-integrated manufacturing (CIM) and (2) strategic information systems. These elements have been integrated into the JIT approach to facilitate flexibility in responding to customer demand. The essence of the conventional JIT approach is continuous improvement activities (kaizen).

STRATEGIC INFORMATION SYSTEM AND CIM

Linkage of marketing, production (manufacturing), and suppliers through an information network (Toyota Network System) allows each component of the company to make timely decisions concerning volume and variety of end products. Changes in consumer preferences and sales trends for certain product types can be swiftly conveyed to the people in product development, sales, production, and parts manufacturing, who can quickly respond to the data. The end result is a more responsive company.

Within the Toyota Network System is a subsystem for in-house production information called the Assembly Line Control System (ALC). The ALC includes information used in computer-aided manufacturing and computer-aided planning systems.

In the development of this strategic information system, Toyota used the basic premises found in the JIT production system. The ALC works as a pull system in which each line and process in each plant requests, receives, and uses only the information it needs at the moment.

This book will show in detail how the above approaches are harmoniously integrated into JIT and how Toyota's new approach can be useful in many ways to a variety of industries.

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Dr. Monden has gained valuable practical knowledge and experience from his research and related activities in the Japanese automobile industry. He was instrumental in introducing the JIT production system to the United States. *Toyota Production System* is recognized as a JIT classic and was awarded the 1984 Nikkei Prize by the Nikkei Economic Journal. However, his research fields are wide, covering not only production and operations management but also managerial and financial accounting, corporate finance, and business economics. His dissertation title was "Basic Research on Transfer Pricing and Profit Allocation in Decentralized Organizations," and his recent research includes "Management of Inter-Firm Networks Based on Incentive Prices."

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Section 1

Total System and Implementation Steps

1

Total Framework of the Toyota Production System

The Toyota Production System was developed and promoted by Toyota Motor Corporation and is being adopted by many Japanese companies in the aftermath of the 1973 oil shock. The main purpose of the system is to eliminate through improvement activities various kinds of waste lying concealed within a company.

Even during periods of slow growth, Toyota could make a profit by decreasing costs through a production system that completely eliminated excessive inventory and workforce. It would probably not be overstating the case to say that this is another revolutionary production management system. It follows the Taylor system (scientific management) and the Ford system (mass-assembly line).

This chapter examines the basic idea behind this production system, how it makes products, and especially the areas where Japanese innovation can be seen. Furthermore, the framework of this production system is examined by presenting its basic ideas and goals with the various tools and methods used for achieving them.

§ 1 PRIMARY PURPOSE

Profit through Cost Reduction

The Toyota Production System is a viable method for making products because it is an effective tool for producing the ultimate goal—profit. To achieve this purpose, the primary goal of the Toyota Production System is cost reduction, or improvement of productivity. Cost reduction and productivity improvement are attained through the elimination of various wastes such as excessive inventory and excessive workforce.

The concept of costs in this context is very broad. It is essentially *cash outlay* to make a profit, discharged in the past, present, and future from sales. Therefore, costs in the Toyota Production System include not only manufacturing costs, but also sales costs, administrative costs, and even capital costs.

Elimination of Overproduction

The principal consideration of the Toyota Production System is to reduce costs by completely eliminating waste. Four kinds of waste can be found in manufacturing production operations:

1. Excessive production resources
2. Overproduction
3. Excessive inventory
4. Unnecessary capital investment

First, waste in manufacturing workplaces is primarily the existence of *excessive production resources*, which are *excessive workforce, excessive facilities*, and *excessive inventory*. When these elements exist in amounts more than necessary, whether they are people, equipment, materials, or products, they only increase cash outlay (costs) and add no value. For instance, having an excessive workforce leads to superfluous personnel costs, having excessive facilities leads to superfluous depreciation costs, and having excessive inventory leads to superfluous cash outlays (capital cost and inventory investment).

Moreover, excessive production resources create the secondary waste—*overproduction*, which was regarded as the worst type of waste at Toyota. Overproduction is to continue working when essential operations should be stopped. Overproduction causes the third type of waste found in manufacturing plants—*excessive inventories*. Extra inventory creates the need for more manpower, equipment, and floor space to transport and stock the inventory. These extra jobs will further make overproduction invisible.

Given the existence of excessive resources, overproduction, and excessive inventory over time, demand for the fourth type of waste would develop. This fourth type, *unnecessary capital investment*, includes the following:

1. Building a warehouse to store extra inventory
2. Hiring extra workers to transport the inventory to the new warehouse
3. Purchasing a fork lift for each transporter
4. Hiring an inventory control clerk to work in the new warehouse
5. Hiring an operator to repair damaged inventory
6. Establishing processes to manage conditions and quantities of different types of inventory
7. Hiring a person to do computerized inventory control

All four sources of waste also raise administrative costs, direct-material costs, direct or indirect labor costs, and overhead costs such as depreciation, etc.

Since excessive workforce is the first waste to occur in the cycle and seems to give way to subsequent wastes, it is very important to first reduce or eliminate that waste. (Figure 1.1 shows the process for eliminating waste and achieving cost reduction.)

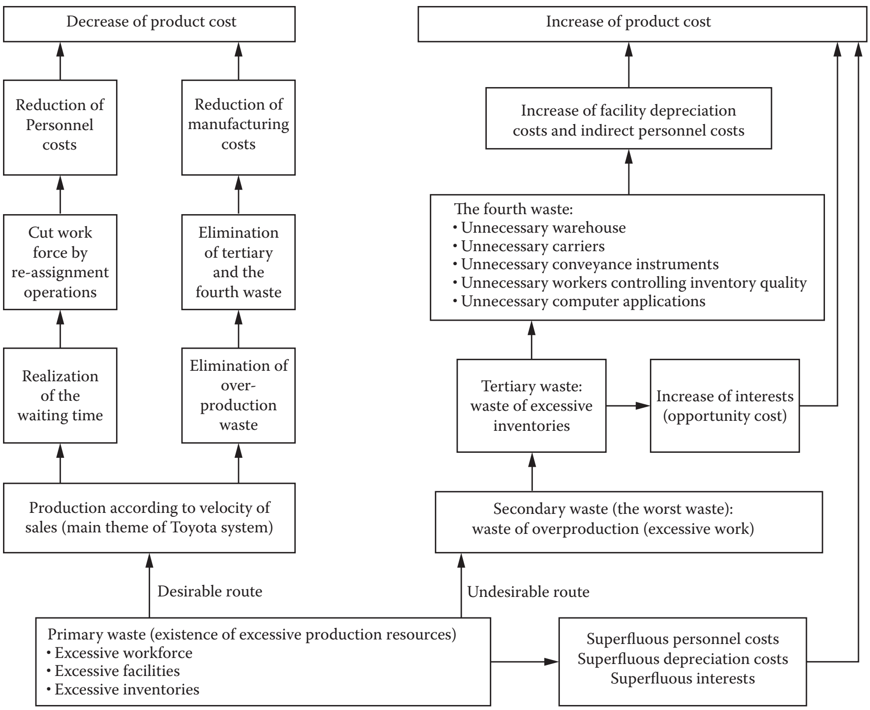

FIGURE 1.1
Process of waste elimination for cost reduction.

By clarifying that an excessive workforce creates idle time (waiting time), worker operations can be re-allocated to decrease the number of workers. This results in reduced labor costs. Furthermore, additional costs caused by the second, third, and fourth wastes mentioned earlier can be reduced.

As seen above, it is the principal subject of the Toyota Production System to control overproduction—to ensure that all processes make products according to the sales velocity of the market. This ability to control overproduction is the structure of the Toyota Production System.

Quantity Control, Quality Assurance, Respect for Humanity

Although cost-reduction is the system's most important goal, it must first meet three other subgoals:

1. Quantity control, which enables the system to adapt to daily and monthly fluctuations in demand of quantity and variety
2. Quality assurance, which assures that each process will supply only good units to subsequent processes
3. Respect for humanity, or morale, which must be cultivated while the system utilizes human resources to attain its cost objectives

It should be emphasized here that these three goals cannot exist independently or be achieved independently without influencing each other or the primary goal of cost reduction. It is a special feature of the Toyota Production System that the primary goal cannot be achieved without realization of the subgoals and vice versa. All goals are outputs of the same system; with productivity as the ultimate purpose and guiding concept, the Toyota Production System strives to realize each of the goals for which it has been designed.

Before discussing the concepts of the Toyota Production System in detail, an overview of this system is in order. The outputs (results)—costs, quantity, quality, and respect for humanity—as well as the inputs of the Toyota Production System are depicted in Figure 1.2.

Just-in-Time and Autonomation

A *continuous flow of production* throughout the company or supply chain, or adaptation to demand changes in quantities and variety, is created by

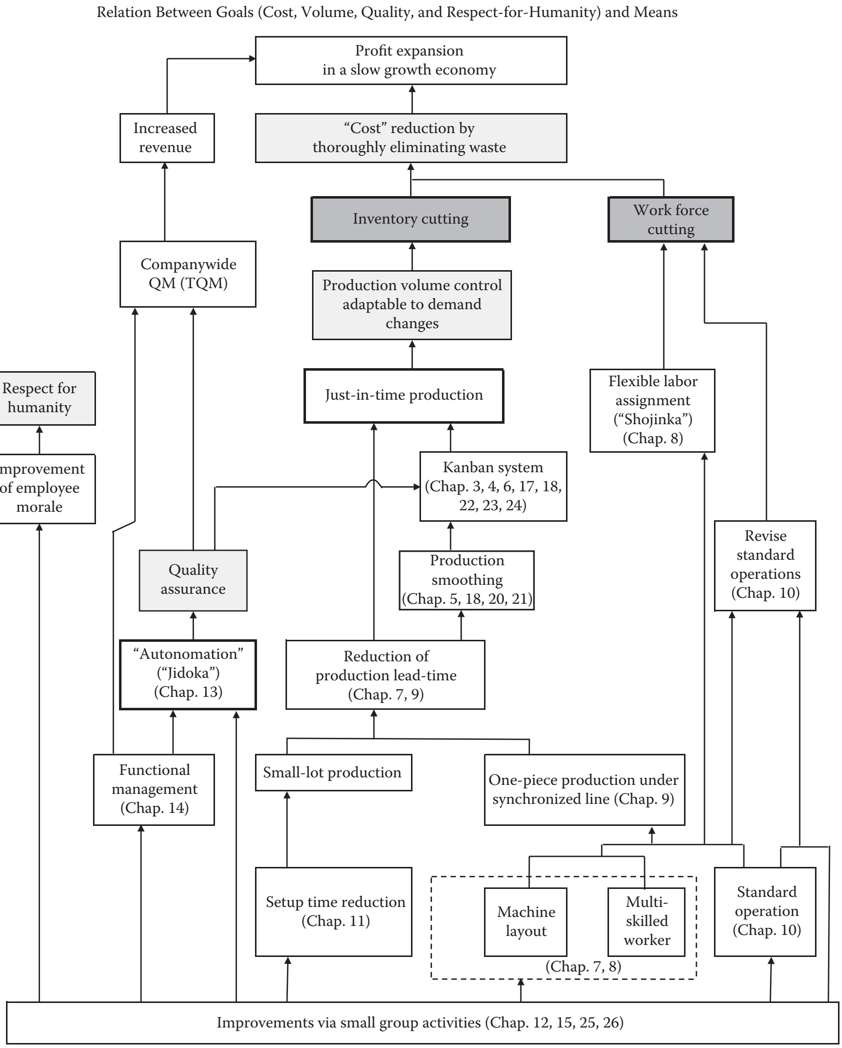

FIGURE 1.2
Framework of the Toyota Production System.

achieving two key concepts: *just-in-time* and *autonomation*. These two concepts are the pillars of the Toyota Production System.

Just-in-time (JIT) basically means to produce the necessary units in the necessary quantities at the necessary time. Autonomation (in Japanese, "Ninben-no-aru Jidoka," which often is abbreviated to "jidoka") may be loosely interpreted as autonomous defects control. It supports JIT by never allowing defective units from a preceding process to flow into and disrupt a subsequent process (see Figure 1.2).

Flexible Workforce and Originality and Ingenuity

Two concepts also key to the Toyota Production System include *flexible workforce* ("Stotinka" in Japanese) which means varying the number of workers to demand changes, and *creative thinking or inventive ideas* ("Seiko"), which means capitalizing on worker suggestions.

To realize these four concepts, Toyota has established the following systems and methods:

- "Kanban system" to maintain JIT production (Chapters 3, 4, 17, 18, 22, 23, 24)
- "Production smoothing method" to adapt to demand changes (Chapters 5, 20, 21)
- "Shortening of the setup time" for reducing the production lead time (Chapter 11)
- "Standardization of operations" to attain line synchronization (Chapter 10)
- "Machine layout" and "multi-function workers" for the flexible workforce concept (Chapters 7, 8)
- "Improvement activities by small groups and suggestion system" to reduce the workforce and increase worker morale (Chapters 12, 25, 26)
- "Visual control system" to achieve the autonomation concept (Chapters 12, 13)
- "Functional management system" to promote company-wide cost control, etc. (Chapters 14, 15)

JIT Production

An example of JIT in the car part assembly process is for the necessary types of subassemblies from the preceding processes to arrive at the product line at the time needed and in the necessary quantities. If JIT is realized in the entire firm, then unnecessary inventories in the factory will be completely eliminated, making stores or warehouses unnecessary. The inventory carrying costs will be diminished and the ratio of capital turnover will be increased. However, it is very difficult to realize JIT in all processes for a product like an automobile if the central planning approach (*push system* by MRP technique), which determines and disseminates production schedules to all processes simultaneously, is used.

Therefore, in the Toyota system it is necessary to look at the production flow conversely; in other words, the people involved in a certain process go to the preceding process to withdraw the necessary units in the necessary quantities at the necessary time. The preceding process produces only enough units to replace those that have been withdrawn. This method is called the *pull system,* which is based on the decentralized system.

§ 2 KANBAN SYSTEM

In this system, the type and quantity of units needed are written on a tag-like card called a "kanban," which is sent from workers of one process to workers of the preceding process. As a result, many processes in a plant are connected to each other. This connecting of processes in a factory allows for better control of quantities needed for various products.

In the Toyota Production System, the kanban system is supported by the following:

- Smoothing of production
- Standardization of jobs
- Reduction of setup time
- Improvement activities
- Design of machine layout
- Autonomation

Maintaining JIT by the Kanban System

Many people incorrectly call the Toyota Production System a kanban system. The Toyota Production System makes products; the kanban system manages the JIT production method. In short, the kanban system is an information system which harmoniously controls the production quantities in every process. Unless the various prerequisites of this system are implemented perfectly (e.g., design of processes, standardization of operations, and smoothing of production), then JIT will be difficult to realize, even when the kanban system is introduced.

A kanban is a card that is usually placed in a rectangular vinyl envelope. Two kinds are mainly used: the *withdrawal kanban* and the *production-ordering kanban*. A withdrawal kanban details the quantity which the subsequent process should withdraw, while a production-ordering kanban shows the quantity which the preceding process must produce.

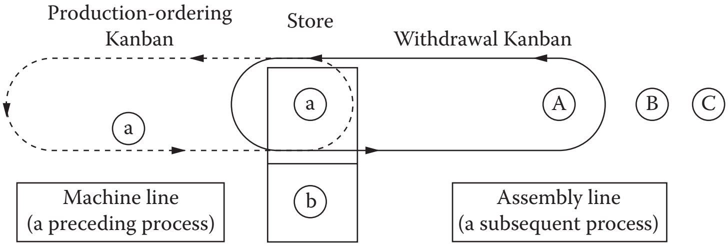

FIGURE 1.3
The flow of two kanban.

Information via Kanban

These cards circulate within Toyota factories, between Toyota and its many cooperative companies, and within the factories of cooperative companies. In this manner, the kanban can convey information on withdrawal and production quantities in order to achieve JIT production.

Suppose we are making products A, B, and C in an assembly line (see Figure 1.3). The parts necessary to produce these products are *a* and *b*, which are produced by the preceding machining line. Parts *a* and *b* are stored behind this line and the production-ordering kanban of the line are attached to them.

The carrier from the assembly line making product A will go to the machining line to withdraw the necessary part *a* with a withdrawal kanban. Then, at store *a*, he picks up as many boxes of this part as the number of withdrawal kanban he has and detaches production-ordering kanban from these boxes. He then brings these boxes back to his assembly line, again with withdrawal kanban.

At this time, the production-ordering kanban are left at store *a* of the machining line showing the number of units withdrawn. These kanban will be the dispatching information to the machining line. Part *a* is then produced in the quantities directed by the number of kanban. The same process is utilized even when a machining line produces more than one type of part.

Adapting to Changing Production Quantities

Let's consider the fine-tuning of production by using a kanban. Assume that a machining process must produce 100 gears per day. The subsequent process requests that five gears per one-time lot be the withdrawal kanban.

These lots are then picked up 20 times per day, which amounts to exactly 100 gears produced daily.

Under such a production plan, if the need occurs to decrease all production processes by 10 percent as a fine-tuning procedure, the subsequent process in this example has to withdraw gears 18 times per day. Then, since the gear machining process produces only 90 units in a day, the remaining hours for 10 units of production will be saved by stopping this process. On the other hand, if there is a need to increase production quantities by 10 percent, the subsequent process must withdraw the gears 22 times per day with the kanban. Then the preceding process has to produce 110 units, and the additional 10 units would be covered by overtime.

Although the Toyota Production System has the production management philosophy that units could be produced without any slack or unnecessary stock, the risk of variations in production needs still exists. This risk is handled by the use of overtime and improvement activities at each process. (Please see Appendix for information on how to cope with the risk of supply chain stoppage after a disaster.)

§ 3 PRODUCTION SMOOTHING

Production in Accordance with Market Demand

The smoothing of production is the most important condition for production by kanban and for minimizing idle time in regard to manpower, equipment, and work-in-process. Production smoothing is the cornerstone of the Toyota Production System.

As described previously, each process goes to its preceding process to withdraw the necessary goods at the necessary time in the necessary quantities. Under such a production rule, if the subsequent process withdraws parts in a fluctuating manner in regard to time or quantity, then the preceding processes should prepare as much inventory, equipment, and manpower as needed to adapt to the peak in the variance of quantities demanded.

Therefore, the assembly line of finished cars, as the final process in the Toyota factory, will produce and convey each type of automobile according to its own time interval within which one unit of the car can be sold on average. (This time span is called *takt time*.) The line will also receive the necessary parts, in similar manner from the preceding processes. (This is called "product mix smoothing.")

In short, a final assembly line produces equally each kind of product in accordance with its own daily takt time. The variation in the withdrawn quantity of each part produced at each subassembly line is minimized, thereby allowing the subassemblies to produce each part at a constant speed or at a fixed quantity per hour. (This is called "parts usage smoothing.") Such a smoothing of production can be illustrated by the following example.

Determining the Daily Production Sequence

Suppose there is a production line that is required to produce 10,000 type A cars in 20 eight-hour operating days in a month. The 10,000 type A cars consist of 5,000 sedans, 2,500 hardtops, and 2,500 wagons. Dividing these numbers by 20 operating days results in 250 sedans, 125 hardtops, and 125 wagons per day. This is the smoothing of production in terms of the *average daily number* of each kind of car produced.

During an eight-hour shift of operation (480 minutes), all 500 units must be produced. Therefore, the *unit takt time*, or the average time required to produce one vehicle of any type, is .96 minutes (480/500) or approximately 57.5 seconds.

The proper mix or *production sequence* can be determined by comparing the actual takt time to produce a specific model of the type A car. For example, the maximum time to produce one type A sedan is determined by dividing shift time (480 minutes) by the number of sedans to be produced in the shift (250); in this sense, the maximum time is 1 minute, 55 seconds. This means that the takt time for a sedan is 1 minute, 55 seconds.

Comparing this time interval with the average takt time of 57.5 seconds, it is obvious that another car of any type could be produced between the time one sedan is completed and the time when another sedan must be produced. So, the basic production sequence is sedan, other, sedan, other, etc.

The maximum time to produce a wagon or a hardtop is 3 minutes, 50 seconds (480/125). Comparing this figure with the takt time of 57.7 seconds, it is obvious that three cars of any type can be produced between each wagon or hardtop. If a wagon follows the first sedan in production, then the production sequence would be sedan, wagon, sedan, hardtop, sedan, wagon, sedan, hardtop, etc. This is an example of the smoothing of production in terms of the takt time of each kind.

Adapting to Product Variety by General-Purpose Machines

Considering the actual manufacturing machines or equipment, a conflict arises between product variety and production smoothing. If a great variety of products is not produced, having specific equipment for mass production will usually be a powerful weapon for cost reduction. At Toyota, however, there are various kinds of cars differentiated in various combinations by types, tires, options, colors, etc. For example, three or four thousand kinds of Coronas are actually produced. To promote smoothed production in such a variety of products, it is necessary to have *general purpose or flexible machines*. By putting certain instruments and tools on these machines, Toyota has specified production processes to accommodate their general usefulness.

The concept of smoothed production as a response to product variety has several advantages. First of all, it enables the production operation to adapt promptly to fluctuations in daily demand by evenly producing various kinds of products every day in a small amount. Second, smoothed production allows for response to the variations in daily customers' orders without relying on product inventories. Third, if all processes achieve a production according to the takt time, balancing between processes will improve and inventories of work-in-process will be eliminated.

Realization of smoothed production requires reducing the production lead time (the time span from the issue of a production order by kanban, etc., through processing, to warehousing) to promptly and in a timely way produce various kinds of products. Reducing lead time then requires shortening the setup time for minimizing the lot size. The ultimate goal of reducing the lot size is a *one-piece* production, which will be discussed later.

§ 4 SHORTENING SETUP TIME

The most difficult point in promoting smoothed production is the setup problem. In a pressing process, for example, common sense dictates that cost reduction can be obtained through continuously using one type of die, thereby allowing for the biggest lot size and reducing setup costs. However, under the situation where the final process has averaged its production and tried to reduce the stocks between the punch-process and its subsequent body line, as if there were an "invisible" conveyer line, the pressing department as a preceding process must make frequent and speedy setups. This means altering the types of dies for the press corresponding to a great variety of products, which are withdrawn frequently by the subsequent process.

During the period of 1945 to 1954 at Toyota, the setup time of the pressing department had been about two or three hours. It was reduced to a quarter-hour in the years 1955–1964, and after 1970, it dropped to only three minutes.

To shorten the setup time, it is important to neatly prepare *in advance* the necessary jigs, tools, the next die and materials, and to remove the detached die and jigs *after* the new die is settled and the machine begins to operate. This phase of setup is called the *external* setup. Also, the worker should concentrate on changing over the dies, jig, tools, and materials according to the specs of the next order *while the machine is stopping*. This phase of setup actions is called the *internal* setup. The most important point is to convert as much as possible of the internal setup to the external setup.

§ 5 PROCESS LAYOUT FOR SHORTENED LEAD TIMES AND ONE-PIECE PRODUCTION

Consider the design or layout of processes in a plant. Previously in this factory, each of five stands of lathes, milling machines, and drilling machines were laid out side by side, and one machine was handled by one worker (e.g., a turner handled only a lathe). According to the Toyota Production System, the layout of machines would be rearranged to smooth the production flow. Therefore, each worker would handle three types of machines. For example, a worker would handle a lathe, a milling machine, and a drilling machine at the same time. This system is called *multi-process handling*. In other words, the single-function worker, a concept which previously prevailed in Toyota factories, has become a *multi-function worker*.

In a multi-process handling line, a worker handles several machines of various processes one by one, and work at each process will proceed only when the worker completes his given jobs within a specified takt time. As a result, the introduction of each unit to the line is balanced by the completion of another unit of finished product, as ordered by the operations of a takt time. Such production is called *one-piece* production and conveyance and may lead to the following benefits:

- As products are created one by one, it is possible to shorten the specified product's production lead time.
- Unnecessary inventory between each process can be eliminated.
- The multi-process worker concept can decrease the number of workers needed, and thereby increase productivity.
- As workers become multi-functional workers, they can participate in the total system of a factory and thereby feel better about their jobs.
- By becoming a multi-functional worker, each worker attains the knowledge to engage in teamwork and help each other.

Such a multi-process worker or multi-functional worker concept is a very Japanese-like method. American and European plants have had excess job divisions and many craft unions until recently. As a result union laborers are paid on the basis of their job class. Because of these agreements, a turner, for example, handles only a lathe and will not usually work on any other kind of machine. In Japan, one enterprise-union to each company is the dominant influence, which makes the mobility of laborers and multi-process handling very easy. Obviously, this difference must be overcome by American and European companies that might wish to adopt the Toyota Production System.

§ 6 STANDARDIZATION OF OPERATIONS

The standard operation at Toyota mainly shows the sequential routine of various operations taken by a worker who handles the multiple kinds of machines of a multi-functional worker.

Two kinds of sheets show standard operations: *the standard operations routine sheet,* which looks like a man-machine chart, and the *standard operation sheet,* which is posted in the factory for all workers to see. This latter sheet specifies the takt time, standard operations routine, and standard quantity of the work in process.

A takt time, or cycle time, is the standard specified number of minutes and seconds that each line must produce one product or one part. The necessary output per month is predetermined from market demand. This time is computed by the following two formulas:

$$\text{necessary output per day} = \frac{\text{necessary output per month}}{\text{operating days per month}}$$

$$\text{takt time or cycle time} = \frac{\text{operating hours per month}}{\text{necessary outputs per day}}$$

Late each month the central planning office conveys to all production departments the required quantity per day and the takt time for the following month. This process is characteristic of the *push system*. In turn, the manager of each process will determine how many workers are necessary for his process to produce one unit of output in a takt time. The workers of the entire factory then must be repositioned so that each process will be operated by a minimum number of workers.

The standard operations routine indicates the sequence of operations that should be taken by a worker in multiple processes of the department. This is the order for a worker to pick up the materials, put them on his machine, and detach them after processing by the machine. This order of operations continues for each machine that he handles. Line synchronization or line balancing can be achieved among workers in this department since each worker will finish all of his operations within the takt time.

The standard quantity of work-in-process is the minimum quantity of work-in-process within a production line, which includes the work attached to machines. Without this quantity of work, the predetermined sequence of various machines in this whole line cannot operate simultaneously. Theoretically, however, if the *invisible conveyor belt* is realized in this line, there is no need to have any inventory among the successive process. The *invisible conveyor belt* allows work pieces to flow one-by-one between successive processes even though the conveyor does not exist.

§ 7 AUTONOMATION

Autonomous Defects Control System

As noted previously, the two pillars that support the Toyota Production System are JIT and autonomation. To realize perfect JIT, 100 percent of defect free units must flow to the subsequent process, and this flow must be rhythmic without interruption. Therefore, quality control must coexist with the JIT operation throughout the kanban system. Autonomation means to build in a mechanism to prevent mass-production of defective work in machines or product lines. The word *autonomation* is not *automation*, but the autonomous check of the abnormal in a process.

The autonomous machine is a machine to which an automatic stopping device is attached. In Toyota factories, almost all machines are autonomous so that mass-production of defects can be prevented and machine breakdowns are automatically checked. One such mechanism to prevent defective work by putting various checking devices on the implements and instruments is called *mistake-proofing* ("bakayoke" or "pokayoke").

Toyota expands autonomation to the manual production line in a different way from the so-called "automation with feedback mechanism." If something abnormal happens in the production line, the worker stops the line by pushing his stop button, thereby stopping the whole line.

Visible Control System

Toyota's *visible control system* is an electric light board called *andon*, which is hung high in a factory so that it can easily be seen by everyone. When a worker calls for help and delays a job, he turns on the yellow light on the andon. If he stopped the line to adjust the machines, the red light would be activated.

§ 8 IMPROVEMENT ACTIVITIES

The Toyota Production System integrates and attains different goals (i.e., quantity control, quality assurance, and respect for humanity) while pursuing its ultimate goal of cost reduction. Improvement activities are a fundamental element of the Toyota Production System and they are what makes the Toyota Production System really tick. Each worker has the chance to make suggestions and propose improvements via a small group called a *Quality Control (QC) circle*. Such a suggestion-making process allows for improvements (1) in quantity control by adapting the standard operations routine to changes in takt time, (2) in quality assurance by preventing recurrence of defective works and machines, and (3) in respect for humanity by allowing each worker to participate in the production process.

§ 9 THE GOAL OF TPS

The Ultimate Goal of TPS

The ultimate goal of the Toyota production system is to improve the company's "efficiency" (or "productivity") in terms of "return on investment" (ROI) or "return on assets" (ROA). This measure is a *corporate* goal and thus it will be the evaluation metric for top management of the company and for the CEO of the business group (the supply chain group as a whole), who must use the consolidated financial statements.

The elements of return on assets are as follows:

$$\begin{aligned}\text{Return on assets} &= \text{Profit margin} \times \text{Asset Turnover}\\ &= (\text{Income/Sales}) \times (\text{Sales/Assets})\end{aligned}$$

Since ROA consists of both margin ratio and turnover ratio, the improvement points can be divided into the following two.

To Improve Margin Ratio, Costs Must Be Reduced, since Profit = Revenue – Costs

In § 1 of this chapter, the concept of costs is defined broadly as "***cash outlay*** to make a profit disbursed ***in the past, present, and future*** from sales. Therefore, costs in the Toyota Production System include not only manufacturing costs, but also sales costs, administrative costs, and even capital costs."[1]

Cost reductions in the design phase are made possible by the techniques of "target costing." The fixed-cost items or the capacity costs can be reduced in the design phase for new models. Cost reductions in the manufacturing phase can be made by the techniques of TPS and "kaizen costing," through which especially variable costs including direct material costs such as parts costs, direct labor costs, and variable overhead

[1] This cash-outlay based concept of costs is the German cost concept of "Pagatorishe Kosten" Begriff, which stands in opposition to the value-consumption based cost concept ("Weltmässige Kosten" Begriff). A cost is considered to be a cash outlay. Even if the timing of consumption of resource values may differ from the cash disbursement, some assumption is introduced to identify the cash outlay. For example, insurance cost is also based on the cash outlay in the past, and we can assume that cash was disbursed to procure the portion of insurance service utilized during a given period (Koch 1958, 355–399).

costs can be reduced. Since the Toyota Production System is applied to the manufacturing stage, it is especially useful for reducing variable costs through kaizen activities and kaizen costing. (For kaizen costing see Chapter 15. See also Monden, Y. *Cost Reduction Systems: Target Costing and Kaizen Costing*, Productivity Press, 1996 for details of target costing and kaizen costing.)

To Improve Turnover Ratio, Lead Time Must Be Reduced

To enhance asset turnover the amount of assets must be reduced in relation to sales. However, the measure of *total* asset turnover (total sales / *total* assets) is not necessarily useful to the supervisors of floor operators in the plant, and so the assets should be confined to inventories that include materials, work-in-process, and final products. Thus the turnover will be the inventory turnover or the number of days' inventory (the numerical examples that follow are just for illustration):

$$\text{Inventory turnover} = \frac{\text{Cost of goods sold}}{\text{Inventory}} = \frac{\$430{,}800}{\$35{,}900} = 12.0$$

Both inventory measures (sales/inventory and cost of goods sold/inventory) have long been utilized in the standard accounting textbooks.

A low ratio of inventory turnover is indicative of slow-moving inventory, and a ratio that is falling or lower than competitors' or both is a sign of potential danger, because it means longer number-of-days' inventory on hand, which is in excess of daily average demand.

$$\begin{array}{c}\text{Number of days'}\\ \text{inventory on hand}\end{array} = \frac{\text{Inventory}}{\text{Cost of goods sold per day}}$$

$$= \frac{\$35{,}900}{\$430{,}800/365} = 30 \text{ days}$$

or

$$= \frac{365 \text{ days}}{\text{Inventory turnover ratio}} = \frac{365}{12.0} = 30 \text{ days}$$

Since the number of days' inventory implies the length of the periods, it is an important portion of the total lead time, showing inventory carrying time. Because the inventory includes materials inventory (including purchased parts), work-in-process inventory, and finished product inventory, we have to reduce the "total" production lead time. Notice that the work-in-process inventory includes both the intra-process and inter-process inventories. If any processing time is reduced, this work-in-process will be reduced.

Another Measure of the Integrated Goal: *"JIT Cash-Flows"*

The internal uses of *cash flows statements* by the managers of a corporation include the following.

The "operating cash flows" in the cash flow statement can be utilized for the following:

- Paying salaries to employees
- Paying for inventory from suppliers
- Paying short-term and long-term liabilities for creditors
- Paying for new facility investments and M&A
- Paying dividends to stockholders

The core of the operating cash-flow, or "JIT Cash Flow," is as follows:*

JIT Cash Flows = Operating income
– (+) Inventory increase (decrease) (1.1)

or

JIT Cash Flows = Sales amount
– Amount of *purchased* direct materials
– All of the *cash-paid* processing costs (1.2)

Equation 1.1 is based on the "indirect method" of measuring the operating cash flows, while Equation 1.2 is based on the "direct method." Although Equations 1.1 and 1.2 are alternative methods for measuring JIT Cash Flow, they are not equivalent with each other because Equation 1.1 has no addition of depreciation on the right side.

Motivational Effects of the *JIT Cash Flow* Measure

Control Measure at the Top Management Level of the Whole Supply-Chain

The "operating income" term in Equation 1.1 will motivate *cost reduction* activities through "kaizen." The "– (+) Inventory increase (or decrease)" term in Equation 1.1 will motivate the reduction of inventory, and thereby total *lead time reduction*.

Thus Equation 1.1, when applied to the consolidated business group, can motivate all member companies in the supply chain to reduce their cost and lead time through kaizen activities. Since the publicly listed companies in a securities market are legally required to report the "consolidated statement of cash flows" and the JIT cash flows is embedded in the operating cash flow section within it, in order to improve the performance of this consolidated statement, the top management or CEO of the consolidated supply-chain group's parent company would inevitably have to increase

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[2] In Equation 1.1 the depreciation expense is not deducted on the right side, but since facility depreciation costs are regarded as "sunk costs" in the JIT production system, it does not matter whether the depreciation is added back in Equation 1.1. If the cash flows from operating activities are accurately expressed in detail, it follows that:

Operating Cash Flows
= **Net income (after interest and tax)**
  + **Non-cash expense (Depreciation)**
    – (+) increase (decrease) in inventory,
    – (+) increase (decrease) in accounts receivables,
    – (+) decrease (increase) in accounts payables,
    – (+) decrease (increase) in accrued liabilities (A)
= **Cash receipts from Sales**
  – **Cash outflows** for:
    purchase of materials,
    processing costs,
    selling expenses,
    administrative expenses, and
    interest expenses and income taxes. (B)

(Here we assume that the disbursements for interest and tax are equivalent to the interest expenses and the income tax payable respectively.)

Equation A on the right side is the "indirect" method, and Equation B is the "direct" method.

Further, the method of measuring operating income based on absorption costing is often criticized as motivating the intentional increase of inventory, because it will transfer part of fixed costs such as depreciation into the inventory thereby decreasing the expenses to be deducted from sales revenue. This criticism, however, is not valid when the increased amount of inventory is subtracted from the absorption-costing based operating income in the JIT cash flows, since all of the fixed costs will eventually be deducted from sales.

net income by reducing costs and at the same time reducing the amount of inventory throughout the supply chain.

However, if sales dealerships are not totally included in this consolidated cash flow statement, since the final product manufacturer has almost no dealer stock (even though the parts suppliers are usually included in it because their stocks are held by the final product manufacturer or parent company), excess inventories in the dealerships will not necessarily be reduced.

In my opinion, as long as the sales dealerships are effectively controlled or governed by the finished products manufacturer, they should be included in the manufacturer's consolidated cash flow statement even if the dealers' stocks are not held by the manufacturer. Or, if dealers are not consolidated with the manufacturer, the term "*– (+) increase (decrease) in accounts receivables*" (see Equation A in footnote 2) is included in the cash flow statement of the manufacturer. To decrease the amount of this term, the final manufacturer has to reduce excess inventories in the dealership by rigorously supplying their products according to the four-step order entry system. (See Chapter 6, § 1, The Order Entry Information System.)

Control Measure at the Level of Plant Managers and Supervisors

JIT Cash Flows in Equation 1.2 = Sales amount
– Amount of *purchased* direct materials
– All of the *cash-paid* processing costs

This measure is a kind of "fractal" of the corporate-wide JIT Cash Flow at the CEO level, which is calculated by the "direct method" of the cash flow statement. Therefore, the JIT cash flows can be used by top managers, middle managers, and lower managers in accordance with "objectives deployment" throughout all layers of the organization.

The JIT cash flow can be measured monthly or daily at each plant and each process or line. The "*mini profit center*" or the "*line company*" systems (described in Chapter 29) use this kind of measure, since it is as easy to compute as daily household accounting.

This measure is calculated by the "direct method" of the cash flow statement, and you can also divide this JIT cash flow figure by the operating labor hours, as the mini profit center system in Kyo-Sera is doing.

Control Measures at the Level of Shop Floor Operators

At the level of floor operators, non-financial measures are useful for goals and performance evaluation. Some physical unit measures and time measures will be used such as the following:

- Lead time
- Inventory size
- Setup-time
- Machine-breakdown
- Defective units
- Capacity availability

To reduce the total lead time to half the current level, the plant manager may suggest that operators reduce each of the above goals to half its current level. How to reduce these subgoals will be described in the following chapters.

The top and middle level managers should reduce the workforce when the demand is reduced in the market and increase the workforce when demand increases. However, in a time of overall recession, they should try to keep employment by "work-sharing," even though they will have to reduce the total wage and salary expenses. Reduction of workforce (i.e., actual lay-off of workers) will prevent improvement activities.

§ 10 SUMMARY

The basic goal of the Toyota Production System is to increase profits or "operating cash flows" by reducing costs or "cash outlays" through completely eliminating waste such as excessive stocks or workforce. To achieve cost reduction, production must promptly and flexibly adapt to changes in market demand without having wasteful slack time. Such an ideal is accomplished by the concept of JIT: producing the necessary items in the necessary quantities at the necessary time.

At Toyota, the kanban system has been developed as a means of dispatching production during a month and managing JIT. Production smoothing to level the quantities and varieties in the withdrawals of parts by the final assembly line is needed for implementing the kanban system (*parts-usage smoothing*). Such smoothing will require the reduction of the production lead time, since various parts must be produced promptly each day. This can be attained by small lot size production or one-piece production and conveyance. The small lot production can be achieved by shortening the setup time, and the one-piece production will be realized by the multi-process worker who works in a multi-process handling line. A standard operations routine will assure the completion of all jobs to process one unit of a product in a takt time. The support of JIT production by 100 percent "good" products will be assured by autonomation (autonomous defects control systems). Finally, improvement activities will contribute to the overall process by modifying standard operations, remedying certain defects, and finally, by increasing worker morale.

Where have these basic ideas come from? What need evoked them? They are believed to have come from the market constraints that characterized the Japanese automobile industry in post-war days—great variety within small quantities of production. Toyota thought consistently, from about 1950, that it would be dangerous to blindly imitate the Ford system (which minimized the average unit cost by producing in large quantities). American techniques of mass production have been good enough in the age of high-grade growth, which lasted until 1973. In the age of low-level growth after the oil shock, however, the Toyota Production System was given more attention and adopted by many industries in Japan to increase profit by decreasing costs or cutting waste.

The Toyota Production System is unique and revolutionary; therefore, when applying this production system outside Japan, special attention and consideration of management-labor relationships and transactions with external companies will be required. See Chapter 19 for an in-depth discussion of applying the Toyota Production System outside of Japan.

2

Implementation Steps for the Toyota Production System

What have been described thus far are the basic methods and concepts of the just-in-time (JIT) production system used at Toyota. However, there is more to successfully implementing JIT than studying the system itself. The steps for introducing a JIT process will be discussed in this chapter.

§ 1 INTRODUCTORY STEPS TO THE TOYOTA PRODUCTION SYSTEM

Step 1: Upper Management Plays a Key Role

Radical changes in top management's consciousness are often triggered by a business crisis caused by environmental or economic changes. Management must saturate every worker with this consciousness and increase profits by motivating workers to decrease costs by thinking of new business innovation.

When introducing JIT, it is important that upper management (not middle or line management) launch the effort to the line workers. Doing so effectively conveys that upper management is in complete support of the change and, in fact, mandates change.

Upper management must provide resources necessary to improve the manufacturing facility. For example, installation of an order entry communication network, a scheduling system, and a supplier delivery system are necessary investments. Management must also realize and recognize that line stops will increase, initially.

Step 2: Establish a Project Team

A project team comprised of plant, department, and section managers should be established and trained in JIT production. A project leader, usually the department manager, is appointed. The project team has two main objectives:

1. To organize seminars and training about JIT concepts and techniques
2. To organize a JIT practice team for sectional and sub-sectional managers

Step 3: Prepare an Implementation Schedule and Set Goals to Be Achieved within the Schedule

The goals include the total lead time, parts and work-in-process inventory, defective products, setup time, machine stoppage, and so on, for the designated period of time scheduled.

Step 4: Introduce a Pilot Project

Because the introduction of a JIT production system calls for revolutionary changes, it is advisable to start small. One manufacturing line should be chosen as a pilot project. Once JIT implementation is successful on that line, other lines can be included until JIT is realized plant-wide.

Step 5: Move from a Downstream Process to an Upstream Process

If the final assembly line is taken as the most downstream process, operations to be performed standing up (rather than sitting) must first be introduced and then the "baton-touch zone" or U-shaped line layout can be introduced, after removing the conveyer. Then "one-piece" production and conveyance can be introduced between the final line and the preceding line. Although the final assembly line has been conducting one-piece production from the beginning, per se, the preceding process should be changed to a line through which single units flow one by one, by introducing the multi-process handling system.

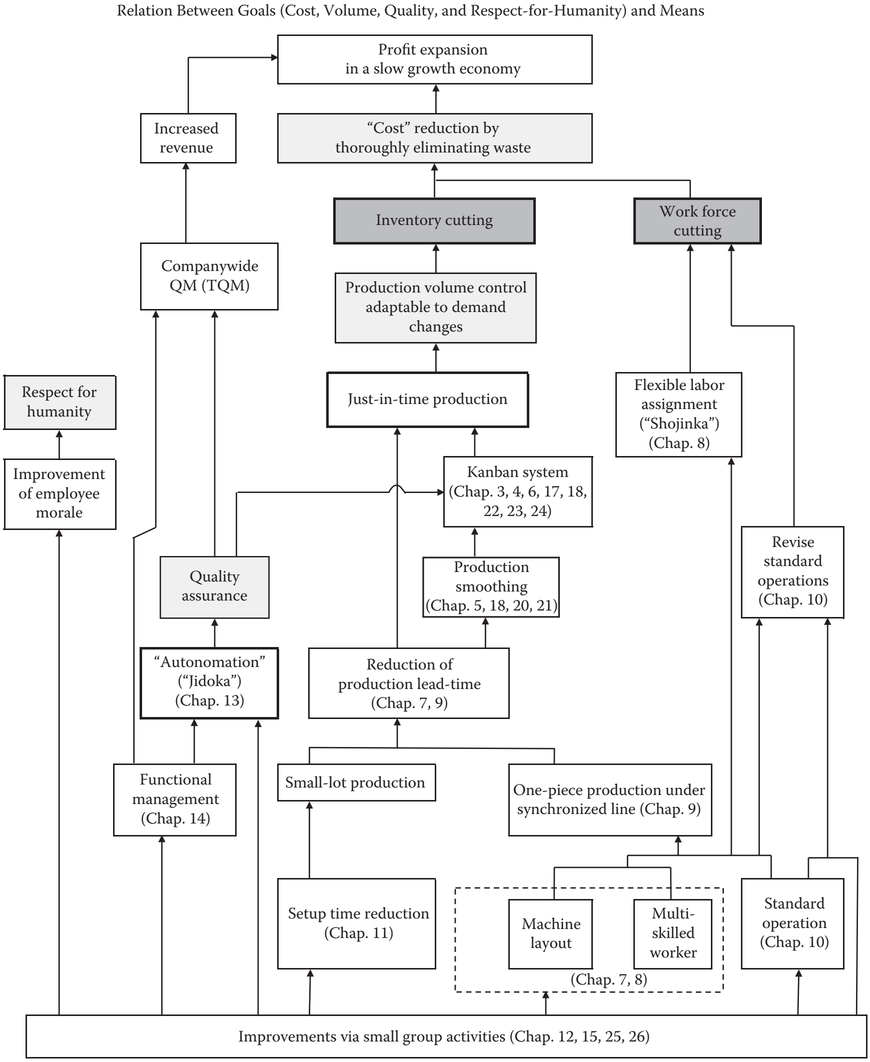


FIGURE 2.1
Framework of the Toyota Production System.

Application Order of JIT Techniques

Implementation of Toyota Production System techniques must be done in the same order as continuous improvement steps are taken. A basic approach is to improve in the direction "from means to goals," corresponding to Figure 2.1, which shows the systemized relationship between goals and means in the Toyota Production System. The direction will be from the lowest box to the highest box in the figure, as follows:

1. Introduction of the 5S foundation for improvement—The foundation for improvements in the workplace is the 5S concept: Seiri (arrangement), Seiton (tidiness), Seiso (cleaning), Seiketsu (cleanliness), and Shitsuke (training). Late delivery and defective goods often occur when the 5S's have not been realized. In such places, worker morale is often low in general.
2. Introduction of "one-piece production" within the synchronized line—Once the 5S concept has prevailed in a plant, the following fundamental prerequisites for JIT should be implemented. Creating a system of "one-piece production" is the most important point to be conscious of in floor improvements.
   a. Change from sitting labor to standing labor
   b. Lay out machinery in process sequence
   c. Connect adjacent processes
   d. Construct U-shaped lines
   e. Deploy multi-process handling by multi-skilled workers
   f. Apply "jidoka" in the sense of separating human operations from machine processing. This makes multi-process handling possible

   Often, there may be resistance from workers or labor unions that reject introduction of "a" and "e" above. Also, implementation of jidoka in the sense used above usually requires help from production engineering staff, because it requires machine improvement.
3. Implementation of small lot size production and improvement of the setup method
4. Introduction of standard operations
   a. Determine the required workforce number for each line, based on takt time
   b. Create a standard operations sheet
5. Implementation of smoothed production by assembling products in response to sales velocity
6. Autonomation ("jidoka")
7. Introduction of kanban cards

In brief, the introductory steps consist of making a schedule, setting a goal, and providing educational activities. Then, starting with 5S, proceed to improvement activities working from downstream to upstream processes. That includes changing machinery layout, standard operations, and finally production smoothing.

§ 2 INTRODUCTION OF JIT AT TOYO ALUMINUM—A CASE STUDY

In this section, a JIT method adopted by Toyo Aluminum Corporation, an aluminum sheet plant, will be discussed as an example. Below is an overview of how they began.

1. A JIT project promotion committee and a practice team were established.
2. The team set a goal to reduce lead time by 50 percent. They then set four subgoals to help realize the final objective.
3. The 5S improvement concept was promoted through quality control circles.
4. A training program on 5S, JIT, TQC, and TPM encompassing every organizational level was developed.

The challenging task of introducing the JIT production system at this plant has been promoted through a GO GO campaign and was followed by a Jump 60 campaign. The GO GO campaign was designed in 1986 to commemorate the 55th anniversary of the company founding. Its purpose was to reduce five main items by 50 percent during a two and one-half year period from June 1985–December 1987. The overview of this plan is depicted in Figure 2.2.

The final target was to reduce total lead time by 50 percent. The first step of their strategy to achieve this goal was to decrease the quantity of work-in-process (WIP) by half and continue improving until the goal was reached. To decrease WIP by 50 percent, three other items would have to be decreased: defective products, setup time, and machinery breakdowns. The reduction in these three items was supported by the 5S concept. Figure 2.3 shows the organization to promote the GO GO campaign.

The committee overseeing the campaign consisted of the divisional managers and five to six operation teams made up of section managers. Under these teams, training groups of shift foremen were directed to study industrial engineering foundations or the KJ method (card system for creating ideas by group members) full time for eight weeks. Additionally, an efficiency improvement team was created to advance the campaign, but actual promotion activities were carried out through the QC circles.

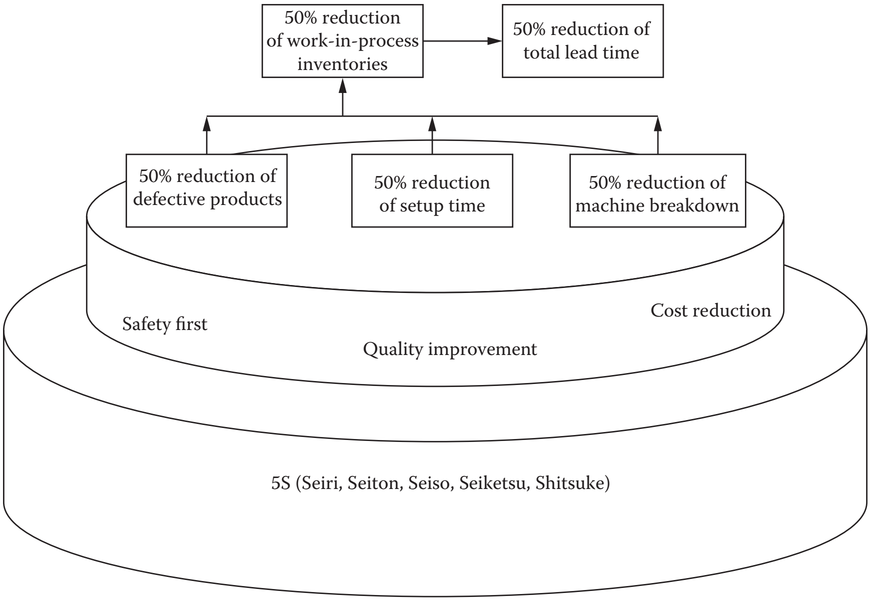


FIGURE 2.2
Target of GO GO campaign.

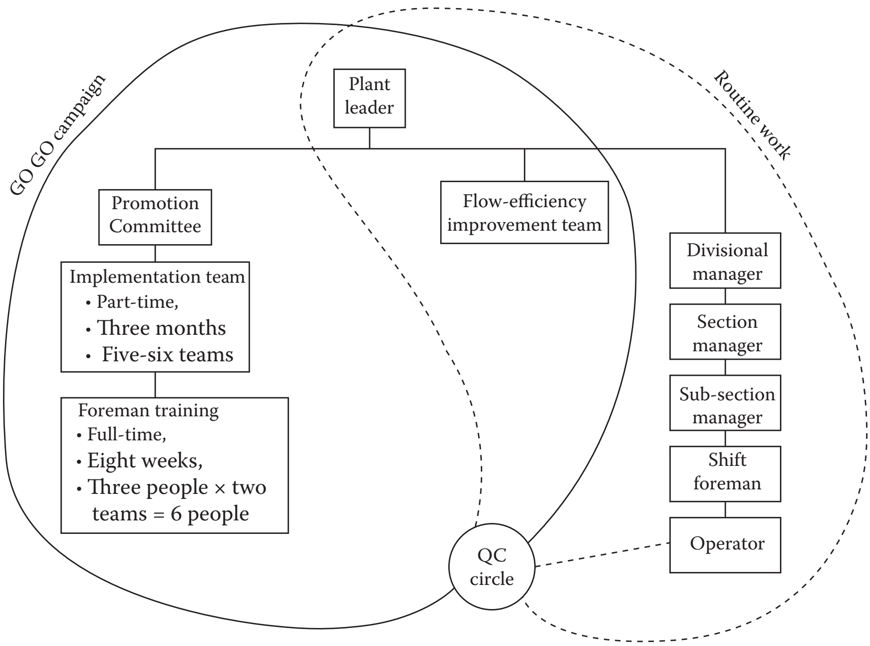


FIGURE 2.3
Structure of GO GO campaign.

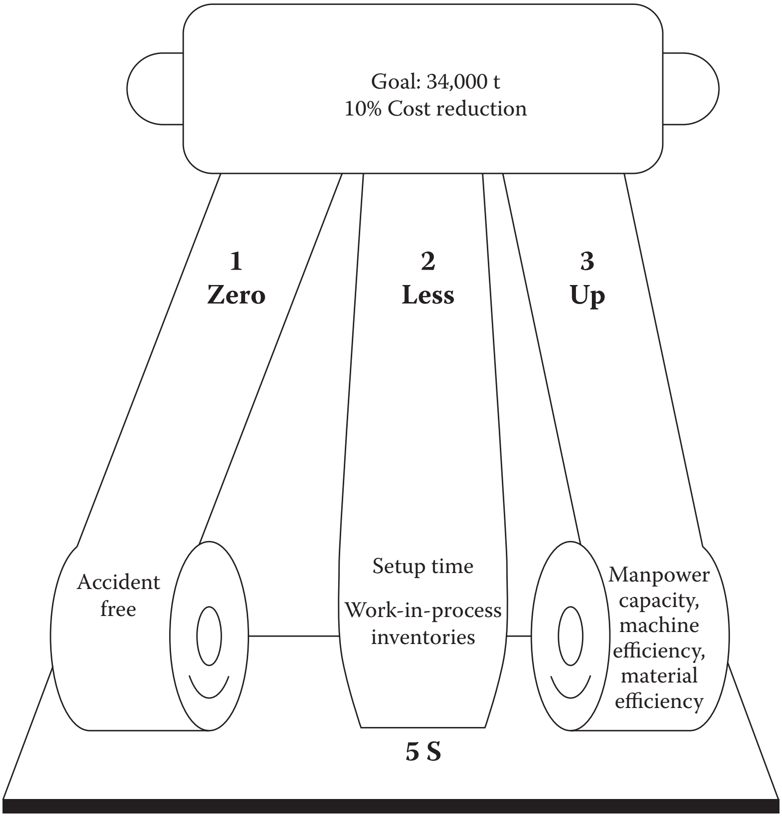


FIGURE 2.4
Goals of JUMP 60 campaign.

The objective of the Jump 60 campaign was to increase productivity and decrease costs by the time the company reached its 60th anniversary in 1991. Most of the goals set in this project were achieved by 1990, even though it was originally scheduled to take three years (1989–1991) to reach the goals.

The goal of 34,000t at the top of Figure 2.4 shows that it was aimed to increase the present production capacity of 31,000t by 10 percent per year without additional capital investment or worker transfers. A subgoal was to diminish the amount of scrap material in order to shorten the total production lead time. Another subgoal was to reduce manufacturing costs by ten percent.

The three subgoals for these reductions are 1 Zero, 2 Less, and 3 Up. *1 Zero* means the plant was accident free. From the time the campaign was started until the author's visit on October 4, 1989, this company had attained 2,440 consecutive accident-free days and was awarded the Labor Minister Prize. One of its purposes was to renew this accident-free record.

2 Less means reduction of setup time and WIP inventories. The company has already reached the subgoal of a 30-minute setup with certain targeted machines, for both the external and internal actions; this project's target was to extend this result horizontally to all machines. As for the targeted machines, the next objective will be to experiment with a new method to realize single setup—setup in less than ten minutes.

A WIP inventory reduction goal was set to decrease inventories by 300t to 1,200t. To meet this goal, smoothed production must be promoted, a kanban system must be applied, and efficiency in small lot production must be attained.

3 Up in the Jump 60 campaign is composed of three components: manpower capacity, machine efficiency, and material efficiency. Manpower capacity is managed by reducing the workforce by using multi-functional workers. This requires an investment in skill development and training. Seminars on JIT, TQC, TPM, and 5S should be offered company-wide. Department and section managers should be allowed to benchmark other organization's methods for solving setup problems, machine breakdowns, and prevention of defects. Improving the efficiency of machines requires eliminating factors disturbing the operating rate (operation at high speeds) and the workable rate (up time of machines). Advancement of material efficiency is checked by continuous quality improvement and by measuring the rate of good products.

In the end, the following formula depicts the total efficiency of facilities:

$$\text{workable rate} \times \text{speed operating rate} \times \text{good product rate}$$

Section 2

Subsystems

3

Adaptable Kanban System Maintains Just-In-Time Production

The *kanban* system is an information system that harmoniously controls the production of the necessary products in the necessary quantities at the necessary time in every process of a factory and also among companies. This is known as *just-in-time* (JIT) production. At Toyota, the kanban system is regarded as a subsystem of the whole Toyota Production System. In other words, the kanban system is not equivalent to the Toyota Production System, although many people erroneously call the latter the kanban system. In this chapter, the various types of kanban, their usages, and their rules are described. How kanban are connected with many supporting routines in production lines is also discussed.

§ 1 PULL SYSTEM FOR JIT PRODUCTION

Toyota's JIT production is a method of adapting to changes due to troubles and demand changes by having all processes produce the necessary goods at the necessary time in the necessary quantities. The first requirement for JIT production is to enable all processes to know accurate timing and required quantity.

In the ordinary production control system, this requirement is met by issuing various production schedules to all of the processes: parts-making processes as well as the final assembly line. These parts processes produce the parts in accordance with their schedules, employing the method of the preceding process supplying the parts to its following process, or, the *push system*. However, this method will make it difficult to promptly adapt to changes caused by trouble at some process or by demand fluctuations.

For adapting to these changes during a month under the ordinary system, the company must change each production schedule for each process simultaneously, and this approach makes it difficult to change the schedules frequently. As a result, the company must hold inventory among all processes in order to absorb troubles and demand changes. Thus, such a system often creates an imbalance of stock between processes, which often leads to dead stock, excessive equipment, and surplus workers when model changes take place.

By contrast, the Toyota system is revolutionary in the sense that the subsequent process will withdraw the parts from the preceding process, a method known as the *pull system*. Since only the final assembly line can accurately know the necessary timing and quantity of parts required, the final assembly line goes to the preceding process to obtain the necessary parts in the necessary quantity at the necessary time for vehicle assembly. The preceding process then produces the parts withdrawn by the subsequent process. Further, each part-producing process withdraws the necessary parts or materials from preceding processes further down the line.

Thus, it is not required during a month to issue simultaneous production schedules to all the processes. Instead, only the final assembly line can be informed of its changed production schedule when assembling each vehicle one by one. In order to inform all processes about necessary timing and quantity of parts production, Toyota uses the kanban.

§ 2 WHAT IS A KANBAN?

A *kanban* is a tool to achieve JIT production. It is a card that is usually put in a rectangular vinyl envelope. Two kinds of kanban are mainly used: a withdrawal kanban and a production-ordering kanban. A *withdrawal* kanban specifies the kind and quantity of product which the subsequent process should withdraw from the preceding process, while a *production-ordering* kanban specifies the kind and quantity of product which the preceding process must produce (Figures 3.1 and 3.2). The production-ordering kanban is often called an in-process kanban or simply a production kanban.

The kanban in Figure 3.1 shows that the preceding process which makes this part is forging, and the carrier of the subsequent process must go to position B-2 of the forging department to withdraw drive pinions. The subsequent process is machining. Each box contains 20 units and the

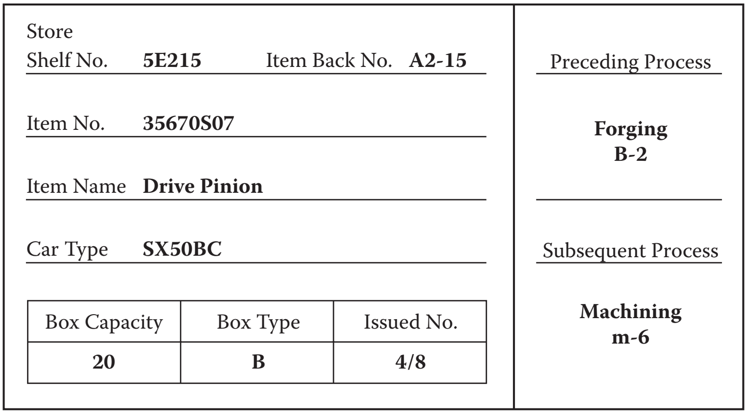


FIGURE 3.1
Withdrawal kanban.

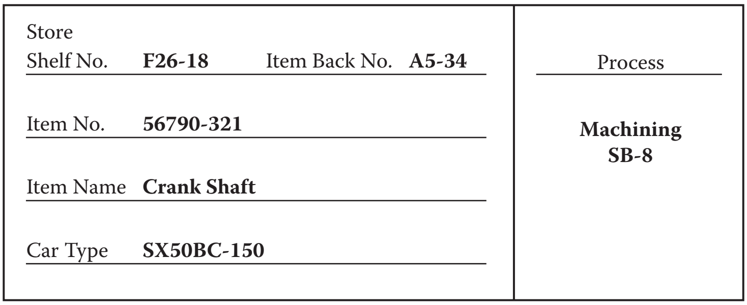


FIGURE 3.2
Production-ordering kanban.

shape of the box is B. This kanban is the fourth of eight sheets issued. The item back number is an abbreviation of the item. The kanban in Figure 3.2 shows that the machining process SB-8 must produce the crankshaft for the car type SX50BC-150. The crankshaft produced should be placed at store F26-18. See Figure 3.3 for a photograph of a withdrawal kanban.

Several other kinds of kanban exist. For making withdrawals from a vendor (a part or materials supplier, also called a subcontractor), a *supplier* kanban (also called a subcontractor kanban) is used. The supplier kanban contains instructions which request the subcontracted supplier to deliver the parts. In the case of Toyota, in principle, the company withdraws parts from the subcontracted factories. However, since the shipping costs are included in the unit price of the part based on the contract, the supplier generally delivers the parts to Toyota. If Toyota actually withdraws the

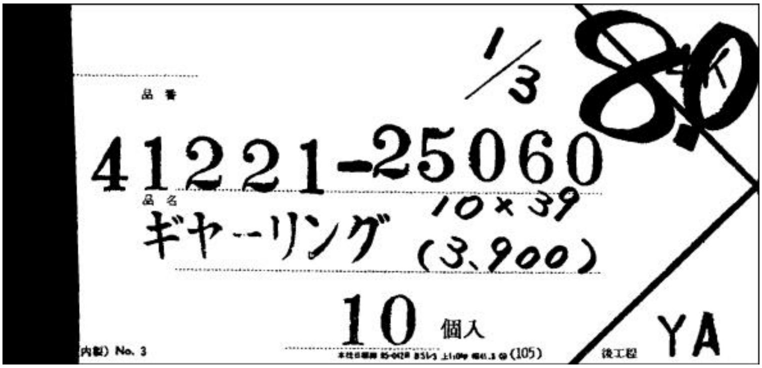


FIGURE 3.3
Actual withdrawal kanban (actual size 4″ × 8″).

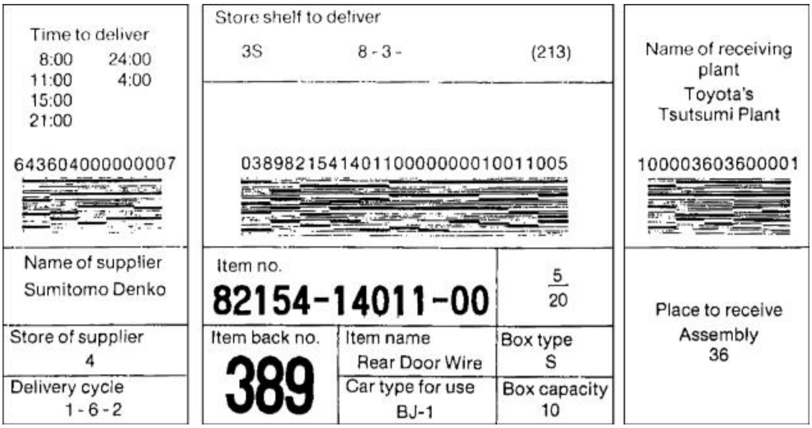


FIGURE 3.4
Detail of supplier kanban.

parts, the shipping cost must be deducted from the part price. Therefore, the supplier kanban is, in its real sense, another type of withdrawal kanban.

Figure 3.4 shows an example of a kanban used for delivery from Sumitomo Denko (a supplier) to Toyota's Tsutsumi plant. Although kanban used within the Toyota plant are not bar coded, all supplier kanban of Toyota are bar coded. The number 36 refers to the receiving station at the plant. The rear-door wire delivered to station 36 will be conveyed to store 3S (8-3-213). The back number of this part is 389.

Since the Toyota Production System engages in small-lot production, frequent transport and delivery each day is necessary. Therefore, delivery times must be written explicitly on this kanban.

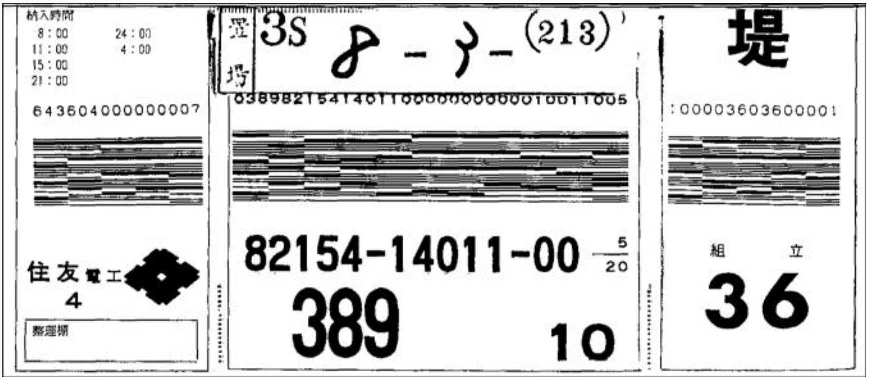


FIGURE 3.5
Actual supplier kanban.

Also, Toyota has no special warehouse; therefore, the receiving place must be written clearly on this kanban. Sometimes in the space under the supplier's name, a notation is written such as "1·6·2," which means that this item must be delivered six times a day and the parts must be conveyed *two delivery times later* after the kanban in question is brought to the supplier. Figure 3.4 is based on the actual supplier kanban pictured in Figure 3.5.

The format of the supplier kanban currently used has changed slightly. Instead of three divided sheets of paper put in a vinyl case manually, the one currently used has been integrated into one sheet of paper put in a vinyl case. Additionally, the bar-code form with horizontal black and white lines has been changed to the vertical form.

Furthermore, all supplier kanban are now being replaced by the electronic kanban. Although both formats are read by a bar-code reader, the electronic kanban is discarded after being read, and its data is automatically transmitted to the supplier. The electronic kanban system is explained in detail in Chapter 23.

Next, to specify lot production in the diecasting, punchpress, or forging processes, a *signal* kanban is used. As seen in Figure 3.6, a signal kanban is tagged to a box within the lot. If withdrawals are made down to the tagged position of this kanban, the production order must be set in motion.

Of the two types of signal kanban, the first one is a *triangular* kanban. In Figure 3.6, when the container positioned *second* from the bottom is withdrawn, the triangular-shaped kanban is detached, and used to direct stamping process #10 to produce 500 units of a left door; the reorder point

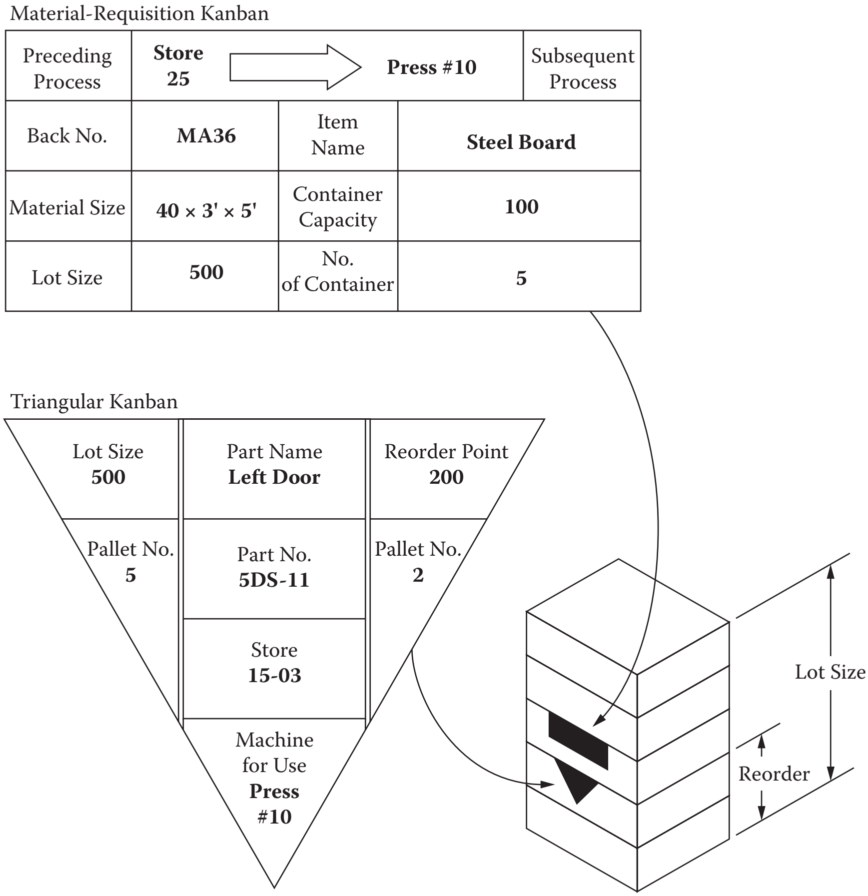


FIGURE 3.6
Signal kanban.

is two boxes or 200 units of a left door. Figure 3.7 shows a triangular kanban for a bracket cab mounting. A triangular kanban is made from a metal sheet and is fairly heavy.

The second type of signal kanban is rectangular-shaped and called a *material-requisition* kanban. In Figure 3.6, when the container positioned *third* from the top is withdrawn by the body welding line, press process #10 must go to store 25 bringing this kanban to withdraw 500 units of a steel board. In this example, the reorder point for material requirements is three boxes of a left door.

See Figure 3.8 for a classification of the main types of kanban.

FIGURE 3.7
Triangular kanban for a bracket cab mounting.

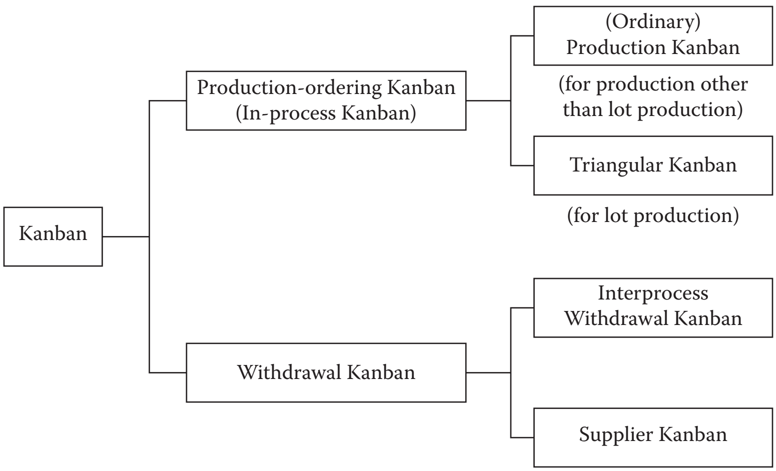


FIGURE 3.8
Framework of the main types of kanban.

How to Use Various Kanban

Figure 3.9 shows how the withdrawal kanban and the production-ordering kanban are used. Starting from the subsequent process, the various steps utilizing the kanban are as follows:

1. The carrier of the subsequent process goes to the store of the preceding process with the withdrawal kanban kept in his withdrawal kanban post (i.e., receiving box or file) and the empty pallets (containers) on a forklift or jeep. He does this at regular predetermined times.

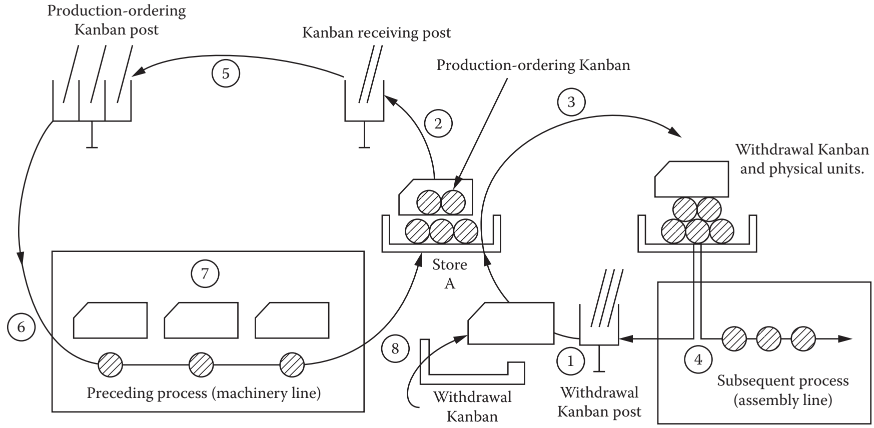


FIGURE 3.9
Steps involved in using a withdrawal and a production-ordering kanban.

2. When the subsequent process carrier withdraws the parts at store A, he detaches the production-ordering kanban that were attached to the physical units in the pallets (note that each pallet has one sheet of kanban) and places these kanban in the kanban receiving post. He also leaves the empty pallets at the place designated by the preceding process people.
3. For each production-ordering kanban that he detached, he attaches in its place one of his withdrawal kanban. When exchanging the two types of kanban, he carefully compares the withdrawal kanban with the production-ordering kanban for consistency.
4. When work begins in the subsequent process, the withdrawal kanban must be put in the withdrawal kanban post.
5. In the preceding process, the production-ordering kanban should be collected from the kanban receiving post at a certain point in time or when a certain number of units have been produced and must be placed in the production-ordering kanban post in the same sequence in which it had been detached at store A.
6. Produce the parts according to the ordinal sequence of the production-ordering kanban in the post.
7. The physical units and the kanban must move as a pair when processed.
8. When the physical units are completed in this process, they and the production-ordering kanban are placed in store A, so that the carrier from the subsequent process can withdraw them at any time.

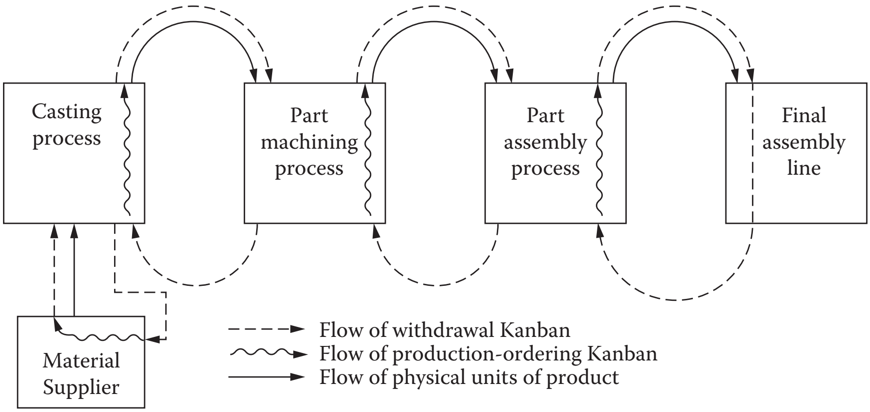


FIGURE 3.10
Chain of kanban and physical units.

Such a chain of two kanban must exist continuously in many of the preceding processes. As a result, every process will receive the necessary kinds of units at a necessary time in the necessary quantities, so that the JIT ideal is realized in every process. The chain of kanban will help realize line balancing for each process to produce its output in accordance with the cycle time (Figure 3.10).

Two Methods of Utilizing Production-Ordering Kanban

One method for using production-ordering kanban is shown in Figure 3.11; it is used to issue many sheets of production-ordering kanban. Each sheet of the kanban corresponds to container capacity. Production is undertaken according to the ordinal sequence in which the kanban were detached from the containers. Where many different kinds of parts exist, kanban are circulated in a manner depicted in Figure 3.11. The classified frames in the kanban post and the classified labels at the store of finished goods are also shown.

The second method uses the single sheet of a signal kanban (Figure 3.6). In the pressing department, for example, the production quantity is so large and the production velocity so rapid that the signal kanban is used.

The signal kanban can be tagged onto the edge of a pallet. At the store, it should be tagged at the position of the reorder point. When the goods at the store are withdrawn and the pallets are picked up, the signal kanban should be moved to the reorder point instructions post. When it is moved to the dispatching post, operations will begin.

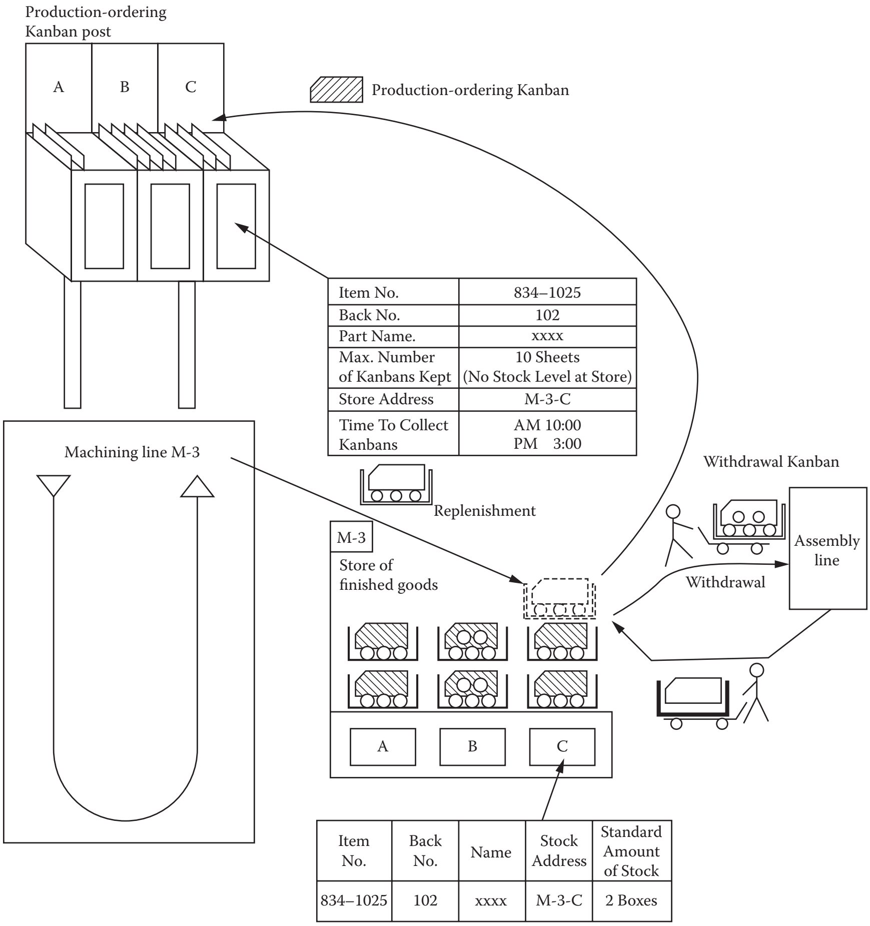


FIGURE 3.11
Ordinal sequence of many kinds of kanban.

According to the ordering point system, when the reorder point and lot size are determined, there is no need to worry about daily production planning and follow-up. Simply keep watch on the timing of orders. This timing is automatically explicit when using the triangular kanban, which orders production, and the rectangular kanban, which directs material requisitions.

If several kinds of parts are produced at a certain process, these triangular kanban can instruct automatically what kind of part should be processed first. That is, production will proceed according to the order in which triangular kanban are detached. For more details on how to use the triangular kanban, see Chapter 17.

§ 3 KANBAN RULES

To realize the JIT purpose of kanban, the following rules must be followed:

Rule 1—The Subsequent Process Should Withdraw the Necessary Products from the Preceding Process in the Necessary Quantities at the Necessary Point in Time

If the production manager alone wished to introduce the kanban system into the factory, his position would be so weak that he could not implement this first kanban rule. To implement this rule, the top management of the company must win over all workers and should also make a critical decision to upset the previous flow of production, transport, and delivery. This decision will probably be met with much resistance because Rule 1 requires a complete change of the existing production system.

The following subrules will also accompany this rule:

- Any withdrawal without a kanban should be prohibited.
- Any withdrawal which is greater than the number of kanban should be prohibited.
- A kanban should always be attached to the physical product.

It should be noted that as prerequisites of the kanban system, the following conditions should be incorporated into the production system: smoothing of production, layout of processes, and standardization of jobs.

The smoothing of production, or leveled daily production, is a necessary condition for a small-lot withdrawal and a small-lot production of subsequent processes, and is most important for implementing Rule 1. For example, if only the kanban system is applied to withdrawing the parts from outside subcontracted companies without any smoothed production in the production line of the manufacturer, then the kanban will be a very dangerous weapon and its original purpose will be lost. Subcontractors need a large amount of inventory, equipment, and manpower to respond to fluctuating demands from the manufacturer.

To use an example from Chapter 1, in the Corona assembly line, sedans are assembled and conveyed every one-unit interval, while hardtops and wagons are assembled and conveyed in three-unit intervals. The final output is then sedan, hardtop, sedan, wagon, sedan, hardtop, and so on.

However, even if Rule 1 was applied, JIT production could not easily be attained because kanban itself is merely a dispatching means for actual production actions during each day at each process. Before entering the phase of dispatching the jobs by kanban, overall planning throughout the plant must be made in advance. For this purpose, Toyota will inform each process and each supplier each month of a predetermined monthly production quantity for the next month's production so each process and each supplier in turn can prepare in advance its cycle time, necessary work force, necessary number of materials, and required improvement point, etc. Based on such overall plans, all processes in the plant can start to apply the Rule 1 simultaneously from the first day of each month.

Concerning withdrawal methods by kanban, two additional features should be mentioned. At Toyota, there are two kinds of withdrawal systems: the *constant-quantity, but inconstant-cycle* withdrawal system, and the *constant-cycle, but inconstant-quantity* withdrawal system. Details of these systems are discussed in Chapter 22; here, two examples will be explained: the method for conveying a set of various parts in constant quantities and the method for conveying parts at a regular time with a round-tour mixed-loading system.

Whirligig

A whirligig beetle is an insect that whirls on the surface of water very swiftly. The carrier in the Toyota factory is also called the whirligig ("Mizusumashi"), because he travels between preceding processes and subsequent processes again and again. For example, when the parts necessary for assembling a small lot of accelerators (five units is a lot size) need to be withdrawn, the carrier will go around various stores at the various machining processes and withdraw the parts necessary to make a set of five accelerators. The whirligig conveyance is a representative example of withdrawing the parts in constant quantities as a set.

Constant-Cycle and Round-Tour Mixed-Loading System

The round-tour mixed-loading system is used by the subcontractor. As far as withdrawals from subcontracted companies are concerned, it is the subcontractor who usually delivers its product to the company. Consequently, the carrying hours become important because of the frequent deliveries due to small-lot production.

For example, four subcontractors, A, B, C, and D, are located in one area and must bring their products to Toyota four times a day in small lot sizes. Although such frequent delivery can decrease the level of inventory remarkably, it is unfeasible for each of the subcontractors because of high distribution costs.

So, the first delivery at 9 a.m. could be made by subcontractor A, also picking up on the way products from companies B, C, and D on A's truck. The second delivery at 11 a.m. could be made by company B similarly picking up the products of A, C, and D on the way. The third delivery at 2 p.m. would be made by company C. This is called the constant cycle, round-tour mixed loading system.

In the United States, however, this system may be hard to apply in some cases. Since America is so wide in a geographical sense, sometimes subcontracted company A might be very far from other subcontractors B, C, or D. To implement the kanban system in such a situation, some additional strategies must be developed, such as exploring the possibilities of hiring subcontractors closer to the manufacturer, decreasing the rate of dependence on subcontractors, or withdrawing parts with a fairly large lot size. Also, in order for the suppliers to respond to frequent withdrawals by the main company, they should adopt the Toyota Production System and shorten their production lead time.

Rule 2—The Preceding Process Should Produce Its Products in the Quantities Withdrawn by the Subsequent Process

When kanban Rules 1 and 2 are observed, all production processes are combined so they become a kind of conveyor line. The balancing of the production timing among all processes will be maintained by strictly observing these two rules. If problems occur in any of the processes, the whole process might stop, but the balance among processes is still maintained. Therefore, the Toyota Production System is a structure which realizes such an ideal conveyor line system, and kanban is a means of connecting all the processes. As a result, the inventory kept by each preceding process will be minimized.

The subrules for the second rule follow:

- Production greater than the number of sheets of kanban must be prohibited.
- When various kinds of parts are to be produced in the preceding process, their production should follow the original sequence in which each kind of kanban has been delivered.

Since the subsequent process will require a single unit or a small lot size to attain smoothed production, the preceding process must make frequent setups according to the frequent requisitions by the subsequent process. Therefore, the preceding process should make each setup very quick.

Rule 3—Defective Products Should Never Be Conveyed to the Subsequent Process

The kanban system itself will be destroyed unless this third rule is followed. If some defective items were discovered by the subsequent process, then the subsequent process itself makes its line stop because it does not have any extra units of inventory, and it sends those defective items back to the preceding process. Such line stoppage of the subsequent process is very obvious and visible to everyone. The system is based on the idea of autonomation described in Chapter 1. Its purpose is simply to prevent recurrence of such defects.

The meaning of defective is expanded to include defective operations. A defective operation is a job for which standardization is not fully attained and inefficiencies then exist in manual operations, routines, and labor hours. Such inefficiencies would likely cause the production of defective items as well. Therefore, these defective operations must be eliminated to assure rhythmic withdrawals from the preceding process. The standardization of jobs is, therefore, one of the prerequisites of a kanban system.

Rule 4—The Number of Kanban Should Be Minimized

Since the number of kanban expresses the maximum inventory of a part, it should be kept as small as possible. Toyota recognizes the inventory level increase as the origin of all kinds of wastes.

The final authority to change the number of kanban is delegated to the supervisor of each process. If he improves his process by decreasing the lot size and shortening the lead time, then his necessary number of kanban can be decreased. Such improvements in his process will contribute to the observance of Rule 4. If it is desired to inspire improved managerial ability, authority to determine the number of kanban must first be delegated.

The total number of each kanban is kept constant. Therefore, when the daily average demand has increased, the lead time should be reduced. This requires the reduction of the *cycle time* of a standard operations routine by changing the allocation of workers in the line. However, because the number of kanban is fixed, a workshop incapable of such improvements will suffer line-stops or force the use of overtime. At Toyota, it is virtually impossible for workers to hide production problems in their workshop, for the kanban system actually visualizes trouble in the form of line-stops or overtime, and will swiftly generate improvement activities to solve the problem. Shops might increase the safety stock or the total number of kanban to adapt to demand increase. As a result, the size of safety inventory can be an indicator of the shop's ability.

In case of a demand decrease, the cycle time of the standard operations routine will be increased. However, the probable idle time of workers must be avoided by reducing the number of workers from the line. Details on how to determine the number of kanban are discussed in Chapter 22.

Rule 5—Kanban Should Be Used to Adapt to Small Fluctuations in Demand (Fine-Tuning of Production by Kanban)

Fine-tuning of production by kanban refers to the kanban system's most remarkable feature: its adaptability to sudden demand changes or exigencies of production.

To illustrate what is meant by adaptability, we will first examine the problems faced by companies using ordinary control systems: that is, companies not using kanban. These companies lack the means to deal smoothly with sudden, unexpected demand changes. The ordinary control system centrally determines production schedules and issues them simultaneously to production processes; therefore, sudden demand changes will require at least a seven- to ten-day interval before schedules can be revised and reissued to the factory—the time interval for the computer to compile and calculate updated data. As a result, the various production processes will be faced from time to time with abrupt, jolting changes in production requirements; these problems will be compounded by the processes' lack of smoothed production.

Companies using the kanban system, on the other hand, do not issue detailed production schedules simultaneously to the preceding processes during a month; each process can only know what to produce when the production-ordering kanban is detached from the container at its store. Only the final assembly line receives a sequence schedule for a day's production, and this schedule is displayed on a computer that specifies each unit to be assembled next. As a result, even though the predetermined monthly plan demanded manufacture of six units of A and four units of B in a day, this proportion may be reversed at day's end. No one has instructed the plan changes to all processes; instead, each change has arisen naturally from market demand and exigencies of production, according to the number of kanban detached.

Here we see the meaning of *fine-tuned production*. Where kanban is used, and production is leveled, it becomes easy to react to changes in the market by producing a few more units than the number predetermined by schedule. For example, 100 units a day must be produced as part of the predetermined plan for January, but on January 10 we find that 120 units per day would be necessary for February. According to Toyota's approach, we will adapt to the change by producing 105 or 107 units daily from January 11 on, instead of keeping at the 100 unit rate for a week or ten-day interval required for the production schedule to be revised—as is the case in ordinary production control systems. Moreover, we will not feel the changed plan, since production at each process is always subject to instruction by kanban.

Such fine-tuning of production by kanban can only adapt to small fluctuations in demand. According to Toyota, demand variations of around 10 percent can be handled by changing only the frequency of kanban transfers without revising the total number of kanban.

In the case of fairly large seasonal changes in demand, or an increase or decrease in actual monthly demand over the predetermined load or the preceding month's load, all of the production lines must be rearranged. That is, the cycle time of each workshop must be recomputed and correspondingly the number of workers in each process must be changed. Otherwise, the total number of each kanban must be increased or decreased.

To cope with the bottom and the peak in variation of demand during the year, top management has to make a decision either to level the sales volume for the whole year, or construct a flexible plan for rearranging all the production lines corresponding to seasonal changes during the year.

Lastly, concerning the adaptability of kanban, it should be noted that the kanban can be used also for parts in unstable use, although the safety stock will be somewhat greater in this case. For example, small iron pieces called balance weights must be attached to the drive shaft of a car by a worker to prevent any irregularity in its gyration. There are five kinds of balance weights, and they must be selected according to the grade of irregularity in the rotation of a shaft. If the rotation is even, no balance weight is necessary. If the rotation is irregular, one or more weights must be attached. Therefore, the demand for these five kinds of balance weights is entirely unstable and cannot be leveled at all.

In Toyota, however, a kanban is attached to these balance weights, too. Since the inventory levels of the five kinds of balance weights will not increase more than the total number of each kanban, the inventory levels and order quantities become measurable, and the safety inventory also can be reasonably controlled.

Although the kanban transfer is made at a regular point in time, the number of kanban for each kind of balance weights will somewhat fluctuate depending on the demand change. However, if we wish to minimize such fluctuations of kanban, we have to improve the manufacturing process itself in some way.

§ 4 OTHER TYPES OF KANBAN

Express Kanban

An express kanban is issued when there is a shortage of a part. Although both the withdrawal kanban and the production-ordering kanban exist for this type of problem, the express kanban is issued only in extraordinary situations and should be collected just after its use (Figure 3.12).

As an example, imagine a situation where the carrier for a subsequent process (assembly line) goes to the store of a preceding process (machining line) and finds that part B has not been sufficiently replenished and is in dire shortage (Figure 3.13). In such a case, the following steps will be taken:

1. The carrier issues the express kanban for the part B and puts it in the express kanban post (often called the *red post*) beside the production ordering kanban post at the machining process.
2. At the same time, the carrier pushes a button for the machining line making the part B. The button used to call various machining lines is installed on a board beside the production-ordering kanban post.
3. On an electric light board called *andon*, a light corresponding to part B will be activated, indicating a spur in part B's production.

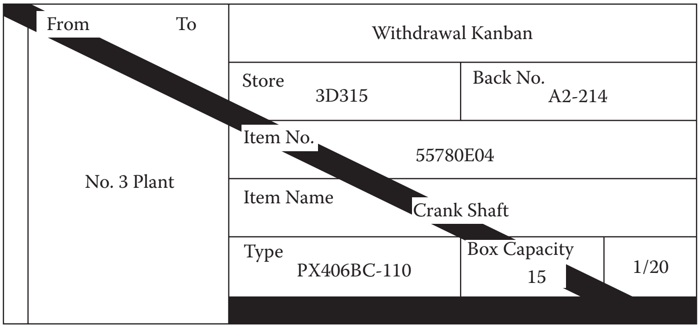


FIGURE 3.12
Express kanban.

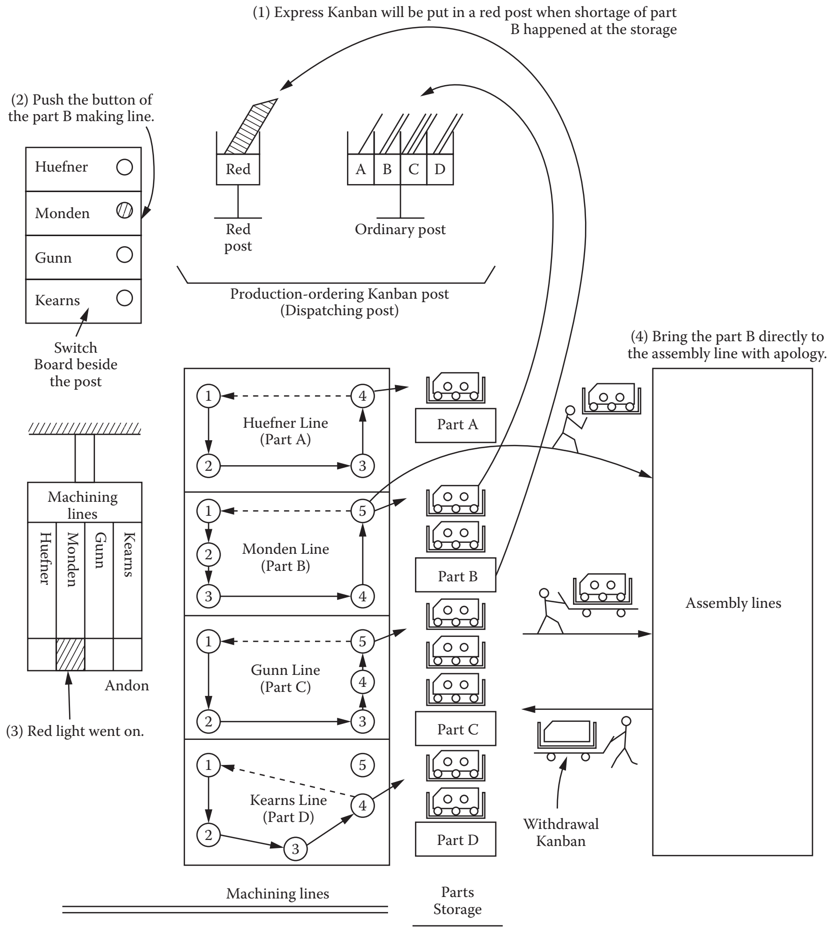


FIGURE 3.13
How express kanban is used.

<table>
<tr><td colspan="3">Production-ordering Kanban</td><td>Process</td></tr>
<tr><td>Store</td><td colspan="2">Back No.</td><td rowspan="4"></td></tr>
<tr><td colspan="3">Item No.</td></tr>
<tr><td colspan="3">Item Name</td></tr>
<tr><td>Car Type</td><td>Container Capacity</td><td>Issued No.</td></tr>
</table>

FIGURE 3.14
Emergency kanban.

4. At that point of the line where the light has come on, the worker must produce the part B immediately, and bring it to the subsequent process (assembly line) himself with apology for its shortage. If the red lamp disappears immediately, the worker will be praised.

Emergency Kanban

An emergency kanban will be issued temporarily when some inventory is required to make up for defective units, machine troubles, extra insertions, or a spurt in a weekend operation. This kanban also takes the form of either a withdrawal kanban or a production kanban, and must be collected just after its use (Figure 3.14).

Job-Order Kanban

While all the aforementioned kanban will be applied to the line of recurrently produced products, a *job-order* kanban is prepared for a job-order production line and is issued for each job order (Figure 3.15).

Through Kanban

If two or more processes are so closely connected with each other that they can be seen as a single process, there is no need to exchange kanban between these adjacent processes. In such a case, a common kanban sheet is used by these multiple processes. Such a kanban is called a *through* kanban (or *tunnel* kanban), and is similar to the "through ticket" used between two adjacent railways. This kanban can be used in those machining lines where each piece of a product produced on a line can be conveyed immediately to the next line by a chute one at a time. Or, this kanban can

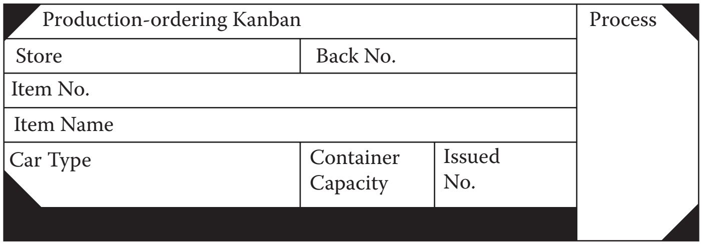


FIGURE 3.15
Job-order kanban.

be used in process plants such as heat treatment, electroplating, scouring, or painting.

Common Kanban

A withdrawal kanban can also be used as a production-ordering kanban if the distance between two processes is very short and one supervisor is supervising both processes.

The carrier of the subsequent process will bring the empty boxes and the *common* kanban to the store of the preceding process. Then, he will bring the kanban to the kanban receiving post (Figure 3.9), and withdraw as many boxes as the number of kanban brought. However, he need not exchange kanban at the store.

Cart or Truck as a Kanban

Kanban is often very effective when used in combination with a cart. In the Honsha plant of Toyota, in order for the final assembly line to withdraw large unit parts such as engines or transmissions, a cart is used which can load only a limited quantity.

In this case, the cart itself also plays a role as a kanban. In other words, when the number of transmissions at the side of the final assembly line is decreased to a certain reorder point (say three or five pieces), then immediately the people engaged in putting transmissions into cars will bring the empty cart to the preceding process, that is, to the transmissions assembly process and withdraw a cart loaded with the necessary transmissions in exchange for the empty cart.

Although a kanban must be attached to the parts as a rule, the number of carts in this case has the same meaning as the number of kanban. The subassembly line (transmission department) cannot continue to make its product unless an empty cart remains, thereby preventing excessive production.

As another example, at the Obu plant of the Toyoda Automatic Loom Works, Ltd. (a supplier of Toyota), the foundry equipment casts the cylinder blocks, crankshafts, motor cases, and so on. In this plant, raw materials such as pig iron and scrap iron are conveyed by a truck from the suppliers to input them into the cupola (furnace). No container or boxes exist to count and load these materials. In this case, the truck is regarded as a sheet of kanban.

Label

A chain conveyor is often used to convey the parts to the assembly line by hanging the parts on hangers. A label specifying which parts, how many and when the parts will be hung is attached to each hanger with a smoothed interval. In this case, a label is used as a kind of kanban, though not actually called kanban, to instruct the worker putting various parts on the hanger from the parts store or the worker assembling various parts at the subassembly line. As a result, the subassembly process can produce only the parts required. A hanger with a label is called a *reserved seat* at Toyota.

A label is also applied to the final assembly line to instruct the sequence schedule of mixed models to be assembled (Figure 3.16 and Figure 3.17).

Full-Work System

Among automated machining or assembly processes where there are no workers, how is it possible for the preceding machine to produce units only in the quantity withdrawn? Differences exist in the capacity and speed of production among various machines, and the preceding machine might continue its processing without considering any problems that might occur in the subsequent machining process.

The *full-work system* is employed with automated machining processes. For example, preceding machine A and subsequent machine B are connected to each other and the standard inventory level of work in process on machine B is six units. If machine B has only four units in process, machine A automatically begins to operate and produce its output until six units are placed in machine B. When machine B is full with the predetermined quantity (six units), a limit switch automatically stops the

Assembly no.			Destination	
Car type		**AJ56P–KFH**		
Rear spring	Rear axle	Booster	Steering lock	Collapsible handle
	S	**M**	**A**	
Def. gear ratio	Free wheel fab.	Electric systems	Exhaust	Transfer
400				
Alternator	Air cleaner	Oil cooler	Heater & air con.	Front winch
500Z			**H**	
Cold-climate oil	Altitude compensation	LLC	Fan	Rear hook
			D	
EDIC				Cold-climate destination
A				

FIGURE 3.16
Sample of a label used at the final assembly line.

operation of machine A. In this way, the standard quantity of work is always placed in each process, thus preventing unnecessary processing in the preceding process (Figure 3.18). Because such electric control by a limit switch has come from the idea of a kanban in a workplace where there are laborers and processes situated far from each other, the full-work system is also called an *electric* kanban.

As another example, suppose the blanking machine (the machine that punches the sheet metal) produces 90 units per minute, whereas the pressing machine in the punching and bending process produces only 60 units per minute. Due to its high capacity, usually the blanking machine

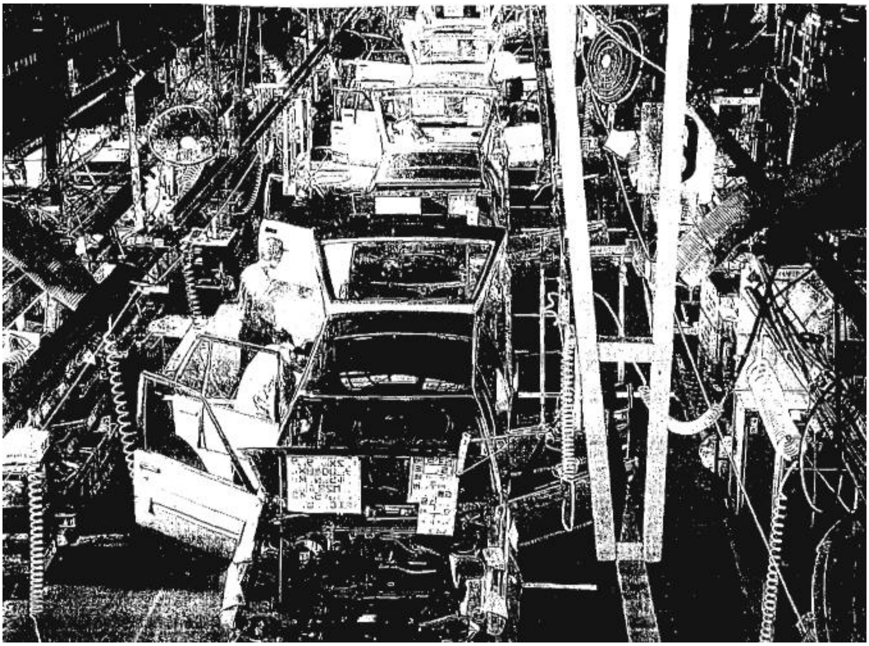


FIGURE 3.17
Samples of labels (broadcasts).

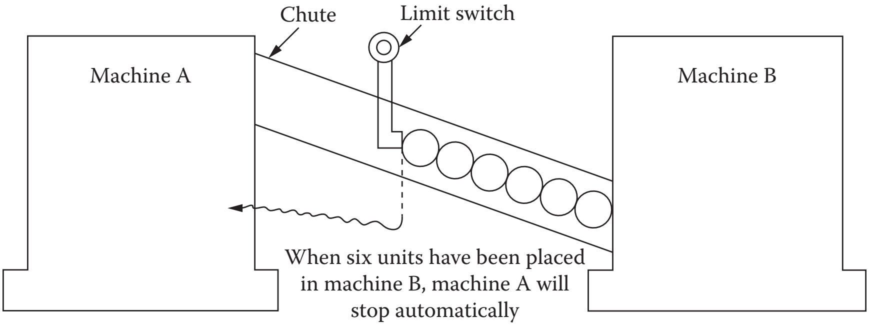


FIGURE 3.18
Full-work system.

operates only during the first two-thirds of the month and is idle the last third. But this method may produce unnecessary inventory in the blanking machine.

Suppose, then, that the blanking machine was directly connected to the pressing machine and the magazine was set between the two. When the magazine is full of punched metal, the blanking machine stops automatically. If only a few units remain in the magazine, the blanking machine automatically starts to operate again. In other words, the blanking machine operates for about two minutes and then rests for about a minute.

At Toyota, to attain line balancing with regard to production quantities, intermittent operation by the full-work system is adopted in all the production lines. This system leads to the following advantages:

- Elimination of unnecessary work-in-process inventory
- Grasping the overall capacity of production lines and disclosing the bottleneck process
- Shortening of the lead time
- Minimization of final product inventory
- Prompt adaptability to changes in demand

4

Supplier Kanban and the Sequence Schedule Used by Suppliers

Sometimes a very powerful manufacturer may instruct suppliers to deliver their parts just-in-time (JIT). In this case, if the manufacturer applied the kanban system to vendors without changing its own production systems, the kanban system would be a demon to the vendors. Although the kanban system is a very effective means to realize the JIT concept, it should not be applied to suppliers without corresponding changes in the overall production system of the user company. The kanban system is merely a subsystem of the Toyota Production System; the Toyota Production System requires an overall rearrangement of existing production systems.

If the subsequent process withdraws parts with large variance in terms of quantity or timing, the preceding process must necessarily prepare slack capacities of manpower, facility, and inventory. In the same way, since the paternal manufacturer is connected to the supplier through the kanban system, the supplier would suffer if the manufacturer ordered parts in a fluctuating manner. Thus, an effort must be made to minimize the fluctuation of production in the final assembly line of the paternal manufacturer.

In 1950, the Honsha plant of Toyota began to install a line-balancing scheme between the final assembly line and machining lines. Then, the kanban system was developed and gradually spread into further preceding processes. As a result, since 1962 the kanban system has been applied to *all* of Toyota's plants. Thus, it was in 1962 that Toyota began to apply kanban to its suppliers. By 1970, Toyota had applied kanban to 60 percent of its vendors. As of 1982, Toyota has applied its *supplier* kanban to 98 percent of its vendors, although still only 50 percent of the vendors are using *in-process* kanban (or, *production-ordering* kanban) in their own plants.

This chapter will cover the following topics:

- Monthly information and daily information provided to the supplier
- Later replenishment system by kanban
- Sequenced withdrawal system by the sequence schedule table
- Problems and countermeasures in applying kanban to the subcontractors
- How supplier kanban should be circulated within the paternal manufacturer

The author collected data for this chapter by interviewing and observing Aisin Seiki Company, Ltd., one of the largest suppliers to Toyota.

§ 1 MONTHLY INFORMATION AND DAILY INFORMATION

Toyota provides two kinds of information to its suppliers: The first is a predetermined monthly production plan, which is communicated to the supplier in the middle of the preceding month. Using this predetermined monthly production plan, the supplier will determine the following planning dates:

1. Cycle time of each process
2. Standard operations routine which rearranges the allocation of workers appropriate to the cycle time at each process
3. Quantities of parts and materials to be ordered to subsuppliers
4. Number of each kanban for subsuppliers

The second type of information is daily information, which specifies the actual number of units to be supplied to the customer company (i.e., Toyota). This daily information takes on two different forms: a kanban or a sequence schedule table (often called a unit order table). These two forms of information are applied alternatively, depending on the withdrawal methods of Toyota.

Toyota uses two types of withdrawal methods: a *later replenishment* system, and a *sequenced withdrawal* system. The later replenishment system ("Ato-Hoju") is a method of using a supplier kanban. Beside the assembly line at Toyota are many boxes which contain parts and supplier kanban. As the parts are used by the assembly line these boxes will become empty, and then at a regular time the empty boxes and their supplier kanban will be conveyed to each respective supplier by truck. From the supplier's store of finished parts, other boxes filled with parts will be withdrawn by the truck.

Let's consider the sequenced withdrawal system. In some cases Toyota may provide a supplier with the sequence schedule for many varieties of finished parts, enabling Toyota to withdraw various parts in a sequence conforming to its sequence schedule for mixed model assembly line. Such a system is called the sequenced withdrawal system ("Junjo-Biki"). For example if the sequence schedule of various automobiles at Toyota's final assembly line is

[A - B - A - C - A - B - A - C - …]

then the sequence schedule of various transmissions to be subassembled by the supplier must be

[Ta - Tb - Ta - Tc - Ta - Tb - Ta - Tc -…]

where *Ta* means the transmission for car A.

§ 2 LATER REPLENISHMENT SYSTEM BY KANBAN

How the Supplier Kanban Should Be Applied to the Supplier

As depicted in Figure 4.1, the flow of a supplier kanban consists of two steps:

1. At 8 a.m., the driver of a truck conveys the supplier kanban to the supplier. This truck also conveys the empty boxes to the supplier.
2. When the truck arrives at the store of the supplier, the driver hands out the supplier kanban to the store workers. Then, the driver immediately mans another truck already bearing the part and its kanban, and drives back to Toyota. In this situation, two matters should be noted:
   a. *The supplier kanban and the supplier's production lead time*. The number of supplier kanban brought to the supplier's store at 8 a.m. does not necessarily correspond to the number of boxes the

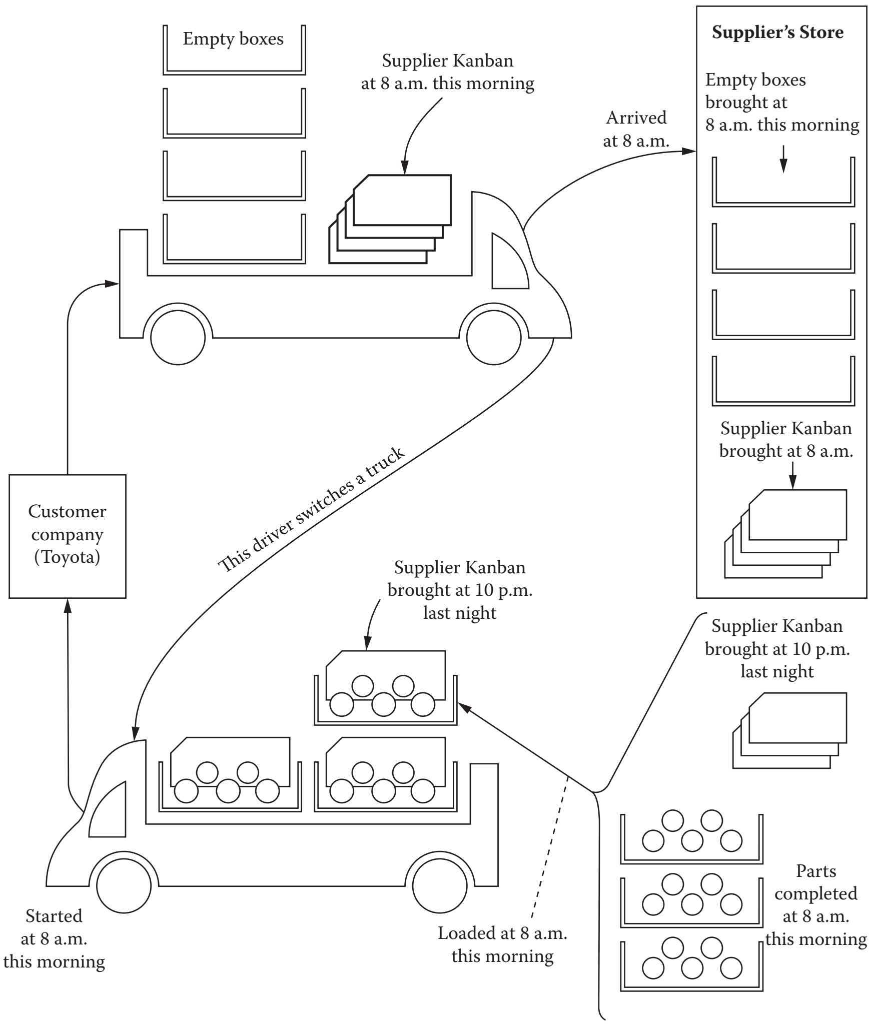


FIGURE 4.1
Flow of supplier kanban.

driver brings back to Toyota at 8 a.m. For example, if parts are conveyed twice a day (8 a.m. and 10 p.m.), we can assume that the supplier kanban contained in the filled boxes at 8 a.m. this morning is the same kanban brought at 10 p.m. last night. (In this case the kanban cycle is "1-2-1." See the remarks on the supplier kanban in Figure 4.1. The time needed for loading the parts on the truck has been omitted to simplify the figure.)

b. *How to use trucks for kanban system: the three-truck system*. The diagrammed situation must involve three trucks. One truck is being driven by the driver, while the other trucks are stationed at Toyota's store for unloading the delivered parts and at the supplier's store for loading the parts. Three people participate: the truck driver and two workers engaged in simultaneous loading and unloading.

Advantages of this conveyance system include the following:

- Shortened conveyance time between the supplier and the paternal manufacturer for the driver has no waiting time, loading time, or unloading time at each store. As a result, the total lead time will be shortened. In other words, the system can eliminate the driver's idle time, since other people load and unload while another truck is on the road.
- While this system's required three trucks have three times the depreciation costs of one truck, the actual duration period is three times one truck. In the long run the system will not increase production costs. On the other hand, if parts are conveyed by only one truck, more than two persons are needed for loading and unloading to reduce total conveyance time as much as possible. These additional workers will increase production costs.
- Although the kanban system requires frequent conveyances, the merits of reducing inventory are immeasurably greater than the increased conveyance costs. Further, the reader should consider the benefits of the mixed loading, traveling conveyance system that Toyota applies to plural suppliers, as explained in Chapter 3.

How the In-Process Kanban Will Circulate in the Supplier's Plant

Suppose again that parts will be withdrawn by the automaker twice a day: 8 a.m. and 10 p.m. To correspond to this time schedule, the production ordering post for a manufacturing process is divided into two frames as depicted in Figure 4.2.

The 8 a.m. file contains as many production kanban as the number of customer kanban brought at 8 a.m., and will instruct production during

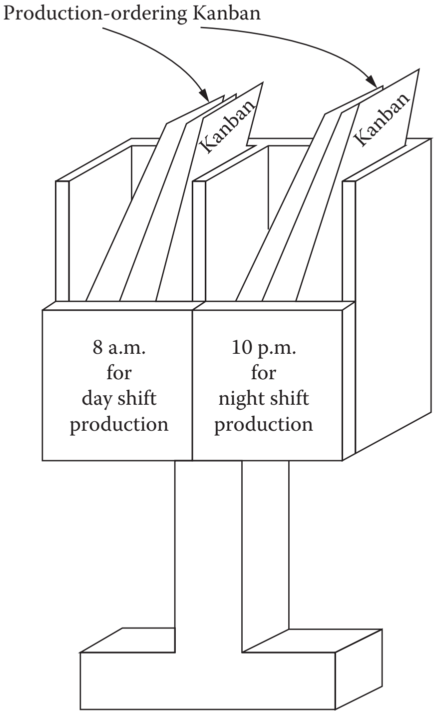


FIGURE 4.2
Production-ordering kanban post (dispatching post).

the day shift. The production of parts will be completed at the latest by 10 p.m. that night, and the parts will be loaded on the truck at 10 p.m. to deliver to Toyota.

The 10 p.m. file contains as many production kanban as the number of customer kanban brought at 10 p.m., and will instruct the production for the night shift.

The required parts will be finished at the latest by 8 a.m. the next morning, and again will be loaded on the truck at 8 a.m. for delivery to Toyota. (Note that for simplicity loading time allowances are not included.) These operations are seen in Figure 4.3.

How the paternal company determines the total number of supplier kanban is detailed in Chapter 22. The number of supplier kanban which a supplier dispatches to the second step subsupplier is determined by applying the same formula. These formulas are calculated by computer. Also, the formula determining the total number of in-process kanban is explained in Chapter 22.

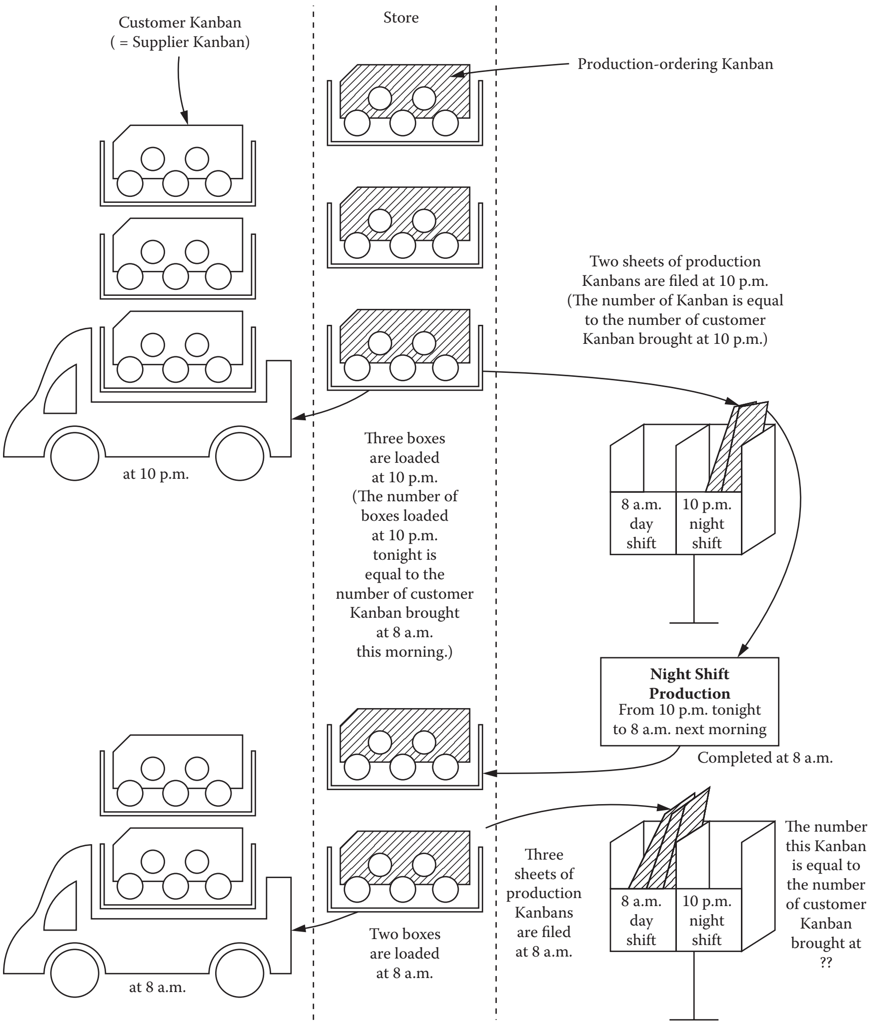


FIGURE 4.3
Flow of customer kanban and in-process kanban.

§ 3 SEQUENCED WITHDRAWAL SYSTEM BY THE SEQUENCE SCHEDULE

Once a day, Toyota communicates the sequence schedule for various parts to the computer office of the vendor's plant. In some cases this sequence information will be recorded on a supplier's diskette allowing the computer to print out labels specifying the details of the parts to be assembled one by one on the supplier's assembly line.

The Shiroyama plant of Aisin Seiki Company, Ltd. (a Toyota supplier), for example, previously relied on a magnetic tape delivered by Toyota, which specified the sequence schedule for the day's production of transmissions. Then, an online computer system between the Shiroyama plant and Toyota became able to communicate the sequence schedule in a real time manner. This is based on value-added network (VAN). This sequence schedule table was called the *unit order table* and is communicated to the assembly line every hour (16 times a day), four hours before the delivery to Toyota. This information flow is depicted in Figure 4.4.

However, Toyota currently transmits the sequence information for parts that are relatively large in size, such as transmissions, engines, accelerators, tires, sheets, and bumpers, to their suppliers via the so-called "e-kanban" (the new type of electronic kanban). Thanks to this e-kanban, larger

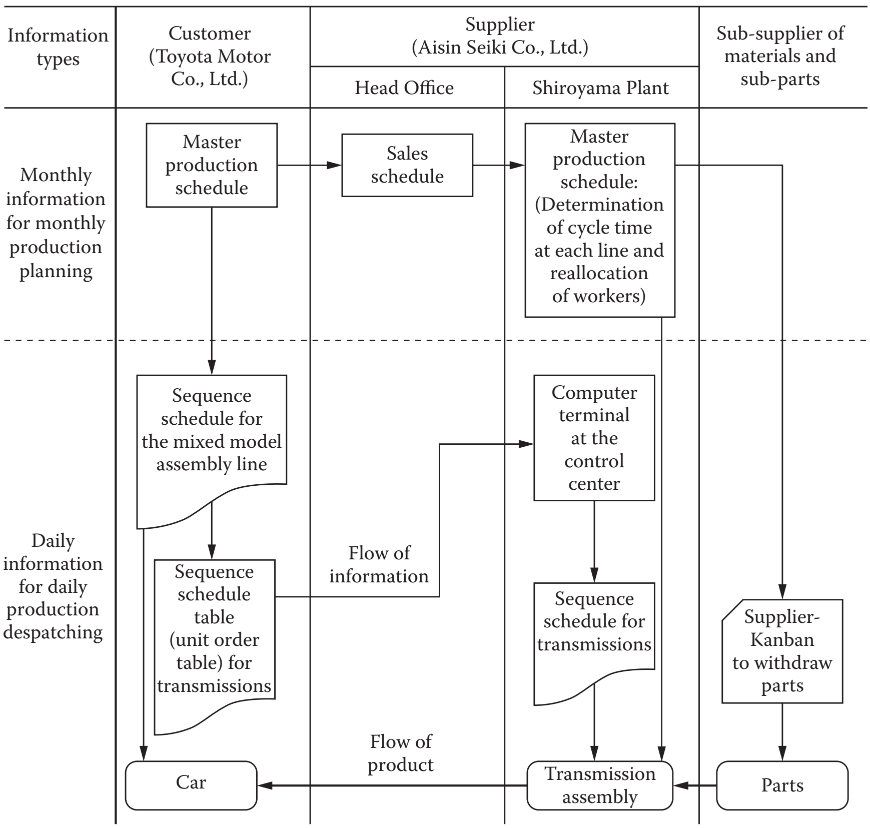


FIGURE 4.4
Information system under the sequenced withdrawal system.

components can be brought to Toyota's assembly plants before Toyota uses them. That is why this kanban is also called the "former replenishment type e-kanban" or the "delivery-in-advance type electronic kanban." For details, see Chapter 23.

On the other hand, there is a supplier kanban used by Aishin in this case (See the right side of Figure 4.4). Currently this kanban is also substituted by another type of kanban, called the "later replenishment type electronic kanban," whose function is almost the same as the conventional supplier kanban, but it differs in transmitting the kanban information via Internet. Again, for details please refer to Chapter 23.

Store Space and a Variety of Products

To reduce the inventory level of a store, it is also necessary to minimize the store's space size. However, the present state of the JIT production system by kanban necessarily assumes that some amount of inventory exists at the store of parts completed by the previous process. The reasons follow:

- When the *constant-quantity and inconstant-cycle withdrawal system* is used, the preceding process must have some inventory of finished parts to adapt to any irregular timing of withdrawals. The timing of withdrawals must necessarily be irregular under this system because of fluctuating *demands in the outside* market.
- When the *constant-cycle and inconstant-quantity withdrawal system* is used, the preceding process must again have some inventory to adapt to inconstant quantities of withdrawals by the subsequent process. Again, under this system, the withdrawn quantity must fluctuate because of the vagaries of customer demand.

Therefore, the ideal of nonstock productions has not yet been realized under the present state of the JIT approach at Toyota, although inventory level has been very well controlled by the kanban itself. Of course, if the ideal of invisible conveyor belt lines is realized throughout the plant, it follows that the nonstock production or *just-on-time* production is attained. Still production at Toyota is far from this ultimate ideal, and the term *just-in-time* is more appropriate for the present situation than the term *just-on-time*.

At Toyota's Kamigo plant, for example, the store of finished products (engines) is classified for delivery to its various client plants and companies.

On the other hand, if the store is classified for a broad variety of finished parts, the total quantities of parts will increase. Therefore, if the size of the part is quite large (for example, transmissions or engines), and its varieties are many, the sequenced withdrawal system must be applied to minimize the store space. However, if the part size is small, the later replenishment system will be applied.

How the Sequence Schedule Is Used in the Assembly Lines of a Supplier

Let us first examine the production situation at the Shiroyama plant of Aisin Seiki Company, Ltd. Its major products and their monthly production volumes (as of 1981) can be seen in Table 4.1. The production characteristics of these products—large variety and short runs—are depicted in Figure 4.5.

TABLE 4.1

Major Products and Their Monthly Production Volume

Products	Volume	Customers
Manual transmission (T/M)	20,000	Toyota Motor Co., Ltd. Daihatsu Kogyo Co., Ltd.
Semi-automatic transmission (for the automobile) (ATM)	3,000	Suzuki Motor Co., Ltd.
Semi-automatic transmission (for the industrial vehicle) (T/C)	1,000	Toyota Automatic Loom Works Co., Ltd. International Harvester Co.
Power steering (P/S)	2,500	Toyota Motor Co., Ltd. Hino Motors Co., Ltd.

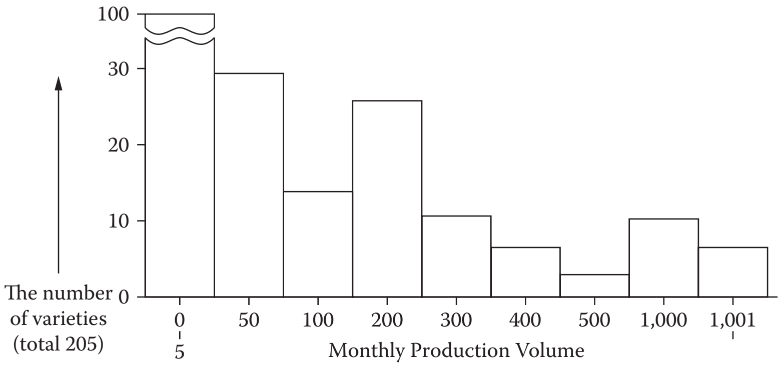


FIGURE 4.5
Production characteristics of a large variety and short run operation.

Model	Basic	4 speeds 5 speeds	Engine gasoline diesel	Frame truck bus	Steering right left	Final model
Variety	1	2	8	- - - - -	- - - - -	► 74

FIGURE 4.6
Design process from a basic model to the final models.

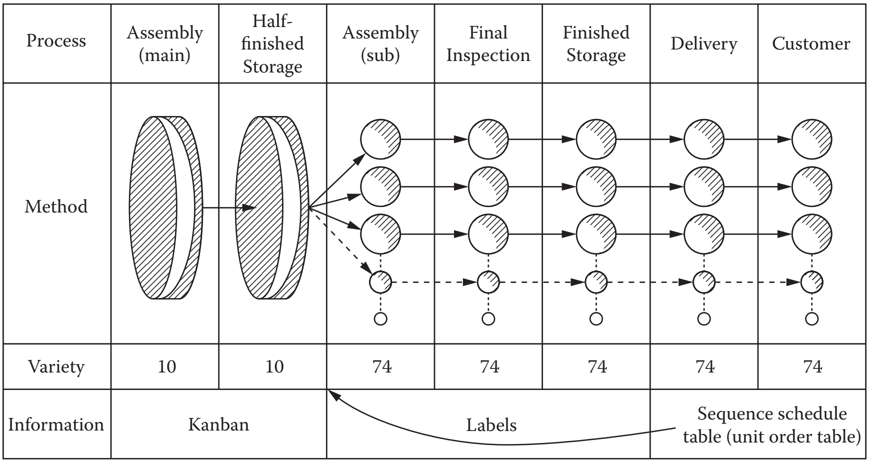


FIGURE 4.7
Information and production method on the assembly lines.

Now we will consider how the Shiroyama plant is coping with such productions of large variety and short runs. Considering the design process, it is possible to expand a basic model transmission to adapt to the large variety of cars in which they will be used (Figure 4.6).

This design process is incorporated into the various assembly lines as seen in Figure 4.7. The assembly line is divided into two parts (main and sub) and storage for half-finished and finished transmissions are installed. This divided assembly line responds to the many varieties of customer's orders. The lead time from the half-finished parts store to the finished parts store is only 15 minutes, and the conveyance to Toyota takes one hour. As a result, these assembly lines can respond to the large variety of orders demanded by Toyota—orders whose sequence information is introduced only four hours before the delivery.

At the head of the subassembly line, a label will be fastened to each transmission one by one, and these labels will sequence the 74 varieties of transmissions completed by the main assembly line. Meanwhile, each semifinished transmission at the main assembly line will receive its own kanban, and successive production of the ten basic transmission types will be ordered by these kanban.

It must be emphasized here that the transmission is a unique example; while in most cases one kanban will dispatch several—say, five—units which will be placed on one pallet, in the case of the transmission, each unit receives its own kanban. The reason for this is that although each transmission is a large unit in itself, production must be able to respond to the large variety of demand. The kanban used in the main assembly line for transmissions has been replaced by the aforementioned "e-kanban."

§ 4 PROBLEMS AND COUNTERMEASURES IN APPLYING THE KANBAN SYSTEM TO SUBCONTRACTORS

There must be some discrepancy between the quantities of parts the paternal company specifies in its monthly predetermined production plan and the quantities it actually orders during the month (based on kanban or the sequence schedule table). This discrepancy is usually about ten percent. However, there is no concept of plan revision in the operating processes of the plants because only production information in the form of kanban or labels is given in a real-time manner.

Concerned by the discrepancy and other related problems which might occur in the transactions between a paternal manufacturer and its subcontractors, the Japanese Communist Party, along with the Japanese Government's Fair Trade Commission, has strongly criticized the Toyota system. The following sections will address their criticism and guidance as well as Toyota's countermeasures, together with the author's opinion on this problem.

Criticism by the Communist Party against the Toyota Production System

The Taylor System was once opposed by American labor unions contending that scientific management neglected humanity and regarded man as a machine. Indeed, so intense did the dispute become that the United States found it necessary to investigate the subject through a special committee.

Just as scientific management once became an issue for the U.S. House of Representatives, the Toyota Production System has also come under the scrutiny of the Japanese House.

In 1977, just four years after the first oil shock hit Japan in late 1973, and when most Japanese companies were still suffering from its effects and the consequent inflation of yen currency, Michiko Tanaka, a member of the House of Representatives and also a member of the Japan Communist Party questioned Premier Takeo Fukuda about the Toyota Production System as follows:

> The management situation of medium and small enterprises is so severe that it can hardly be compared with big companies. However, the supplementary budget at this time restricts the amount of loans and cannot offer a promising future to the minor companies.
>
> Especially severe are the problems faced by subcontractors, who supply sixty percent of manufacturers. For example, the Toyota Motor Company, Ltd. has earned the current profit of 210 billion yen (about $1 billion). Behind this huge profit how many subcontractors have dropped tears? Toyota's completely rationalized production system strictly instructs its subcontractors to deliver the required parts within today or by tomorrow. Therefore, there is no excessive parts inventory at Toyota, and thus there is no warehouse and no sleeping funds invested in the inventory.
>
> However, subcontractors are in a precarious situation if they occupy positions as low as the third, fourth or fifth steps in the vertical line among manufacturers. The reason is if they cannot deliver their parts just in time for the needs of the paternal company, the contracts will be cancelled. Thus, they must engage in estimated production, and if their estimates were mistaken, they have to undertake all the loss themselves. Though payment remains unchanged or is actually decreased, the subcontractors must put up with severe conditions to get their contracts.
>
> Moreover, a serious matter which cannot go unnoticed is that this Toyota system is now prevailing among many industries and a vast number of subcontractors are likely to fall victims to this system. If this practice of bullying the subcontractors is left unrestricted, the Japanese economy will be thrown into chaos.
>
> You have said that you will initiate a compassionate policy in behalf of medium and small enterprises, but how do you cope with these very wicked methods which take a superior position? I would like to hear your belief. (Proceedings at the Japanese House of Representatives, No. 4: October 7, 1977, p. 63)

Fukuda responded as follows:

> Now, concerning your opinion on Toyota's rationalized production system, I hear that the Fair Trade Commission is now guiding the company. The government will also give assurance that the paternal manufacturer will not force its rationalization at the sacrifice of the subcontractor's interests. This is my conviction. (Proceedings, op. cit. p. 65)

§ 5 GUIDANCE BY THE FAIR TRADE COMMISSION BASED ON THE SUBCONTRACTORS LAW AND THE ANTI-MONOPOLY LAW

Thus, the Fair Trade Commission and the Small and Medium Enterprises agency of the government in Japan have guided the paternal manufacturers not to violate the Subcontractor's Law and the Anti-Monopoly Law. The Subcontractors Law is an abbreviation of the "Anti-Deferment-of-Payment-to-the-Subcontractors Law." This law was established in 1956 to maintain a fair subcontracting trade and to guard the subcontractors' interests.

The problematic points of the kanban system which concerned the Fair Trade Commission were as follows:

1. *When production is managed by the kanban system the ordering time is obscure.* According to the Toyota Production System, it is only during the last 11 days of a previous month that a supplier will be notified of the predetermined monthly production plan concerning specific items, quantities, dates and times, and so on. On the other hand, the kanban system and the sequence schedule specify similar information. Therefore, the ordering time is not obvious: is it the time specified by predetermined monthly production plan, or by the kanban and the sequence schedule?

   However, according to the Subcontractor's Law (Article III), even though the ordering action by a paternal maker is an informal notification, the point in time when the instruction is concretely made is regarded as the ordering time.

2. *According to the kanban system there must be some discrepancy between the monthly quantity that is informally ordered and the quantity actually delivered by kanban dispatchings.* In other words, the essence of the kanban system lies in fine-tuning production or making minor adaptations to demand changes.

   When the quantity of goods dispatched by the kanban turns out to be smaller than the quantity originally ordered by the monthly informally communicated master production schedule, the difference must be regarded as the rejection of acceptance, because Article I states that the actual order occurs when the supplier receives instructions from the informal production table.

   In addition, the Subcontractor's Law (Article IV-I-1), prohibits the paternal manufacturer from rejecting all or part of the delivered goods it has ordered.
3. *The kanban delivery system should not be forced on the supplier.* According to the Japanese Anti-Monopoly Law (Article 19): "A business company must not use unfair trading methods." In 1953, as an example of unfair trading methods, the following action was cited: "Realizing its superior position in regard to a dependent company, a business company must not trade with conditions exceptionally unfavorable to the other company in the light of normal business conventions."

   Therefore, when applying the kanban system to its supplier, a paternal company must secure an agreement with the subcontractor, and should never force implementation in a one-sided manner. In the trading contract, it should be noted that without such agreement the kanban system will not be applied. Also, even if the subcontractor agrees to the application of kanban, it must receive an adequate preparation period in order for it to adjust to the new system. Further, the paternal company should not urge the introduction of kanban on vendors without adjusting the technical prerequisites of its own plant and without having full knowledge about the whole Toyota Production System.

The other possible detrimental effects that kanban may have on the subcontractor follow (referring to the paper of Mr. Hyogo Kikuchi, subcontract section manager of the Fair Trade Commission).

Most of the first-step subcontractors that adopted the kanban system are enjoying the same advantages as Toyota. However, the second, third or fourth preceding step subcontractors may suffer from certain detrimental effects for which, essentially, the paternal companies are responsible. These detriments are as follows:

- The subcontractors may have to increase their inventory to achieve the expected production, since they have to deliver parts as quickly as possible in response to withdrawal by kanban. They may also have to utilize overtime to cope with the unexpected. Such increase of inventory in the stores of subcontractors is a consequence similar to situation effected by the Cock System (or, "On-the-Premises Warehouse System") which was popular in Japan after World War II. In the Cock System, a subcontractor will hold a certain amount of its finished parts inventory and bear the risk himself by borrowing a part of the paternal maker's factory. Thus, the paternal maker could use the necessary items in the necessary quantities at the necessary time (JIT), and could issue the order sheet at the time of withdrawal. This system was criticized as a violation of the Subcontractor's Law, and the paternal manufacturers were dissuaded from its use.
- Notwithstanding standard increases in the quantity of monthly delivery, application of the kanban system will increase overall conveyance times. The resulting increases in conveyance expenses will obviously increase the subcontractor's overall costs.
- The most important prerequisite of JIT production is production smoothing, or small lot production. When implemented by a large, paternal manufacturer, this process requires the installment of multi-purpose machines and speedy setup actions. However, this brings up the subcontractor's obligation to install the same multipurpose machines and improved setup actions in order to supply the part at the price which the user company has calculated based on its own smoothed, well-equipped production.

How Toyota Is Coping with Criticism

The main problem pointed out by the Fair Trade Commission was the discrepancy between quantities ordered by the predetermined monthly production plan and the daily kanban or sequence schedule instructions.

Toyota countered this problem as follows:

- Toyota is trying to hold the aforementioned discrepancies down to less than ten percent of the monthly plan, and is requesting that suppliers allow this much difference.
- Since a model of an automobile will usually be produced for about four years, the supplier will not suffer seriously from monthly fluctuations, for these fluctuations are averaged out over many months.
- Toyota is promising its suppliers that it will give advance notice when it is about to stop production of a certain model. At that time it will establish a compensation structure.
- Toyota is telling its suppliers not to start production until instructed by the kanban. Therefore, overproduction is not likely to occur.
- In order for the supplier to adjust to order-oriented production, it must shorten production lead time. Toyota is teaching how to achieve such reductions.

As a result of these steps, there is almost no confusion among Toyota's suppliers caused by plan revisions ordered by kanban. The author especially supports Toyota's countermeasure number two. When a dealer's demands are declining, the actual quantity of goods withdrawn by kanban is likely to be less than the monthly predetermined quantity.

If Toyota was to withdraw this difference in quantity at the end of the month in question, the informally instructed quantity for the next month would be correspondingly smaller than the quantity previously forecasted, and as a result the subcontractor would be surprised to see a sudden, steep drop in his orders. This would never happen at Toyota. According to its production system, Toyota withdraws only the quantity which corresponds as closely as possible to actual demand during the month. To achieve this approach, the quantities ordered both by kanban and by the monthly predetermined instruction must be smoothed in daily production levels. As a result, the supplier would not be confused by the sudden fall in the actual ordered units. The supplier could adapt to the demand change smoothly by fine-tuning each month. The most remarkable advantage of the kanban system, the adaptation to demand change by smoothing the changes of a plan, will begin to function at this point.

In regard to the various problems cited by the subcontract section of the Fair Trade Commission, the author holds the following opinions:

- Concerning the supplier's risk of holding of a large inventory, most of this problem will be resolved if the paternal manufacturer completes the various prerequisites of the kanban system, especially the smoothing of production. Therefore, if this problem does arise, the kanban system is guiltless and the paternal company must be blamed. On the other hand, suppose a supplier is supplying parts to several manufacturers and only some of the manufacturers are applying kanban to the supplier. This supplier might have problems even if the manufacturers using kanban are completing the prerequisite conditions. However, since so many Japanese industries have adopted kanban, this problem is diminishing. The use of kanban is especially widespread throughout the auto industry.
- As for the problem of increased conveyance costs due to more frequent withdrawals, it can be solved by the round-tour mixed loading system and the three-truck system explained earlier in this chapter. If large geographic distances prevent the effective use of such systems, as in the case of the United States, the following approaches can be considered:
    a. Instead of relying on subcontractors, the paternal manufacturer should incorporate parts producing processes in its own factory. In the United States, automobile makers do not rely on subcontractors as much as Japanese automakers.
    b. Instead of making frequent orders to suppliers in small lot sizes, the user company should order in fairly large lot sizes. This practice can be seen in the case of Japanese automakers sending parts to foreign countries for overseas production. Kawasaki Motors U.S.A. is a good example of a company that has adopted the Toyota Production System in the United States (1979).
- As for the difficulty the subcontractor may face in offering a part at the instructed price, such a problem can be resolved if the subcontractor itself adopts the Toyota Production System. This problem also relates to the first problem. Even if the paternal maker has smoothed its production, the subcontractor might not be able to decrease his inventory and at the same time handle frequent withdrawals unless he can change his dies quickly.

Although Toyota is making an effort to keep monthly discrepancies down below 10 percent, some of the suppliers have reported that differences may run to plus-or-minus 20 percent of the initial monthly plan. However, if they are able to adapt to such demand changes in their own processes, this discrepancy does not pose serious problems. For example, the Kariya plant of Aisin Seiki Company, Ltd., has 0.7 days of safety stock ready for delivery to the customer. This means that it delivers parts three times a day to its customer, while holding safety inventory equivalent to two deliveries per day (i.e., 2/3 = 0.7). The level of safety stock indicates the supplier's ability to adapt.

Therefore, subcontractors must also rationalize their production systems. They should not succumb to the easy attitude that rationalization must only be carried out by paternal manufacturers, for rationalization decreases costs, and cost reduction is a shared obligation of both manufacturers and subcontractors.

Figure 4.8 shows that most of the big suppliers of Toyota were once part of the Toyota Motor Corporation. Since each of them can be seen as simply another production process of the Toyota plant, the aforementioned problems do not exist among these companies.

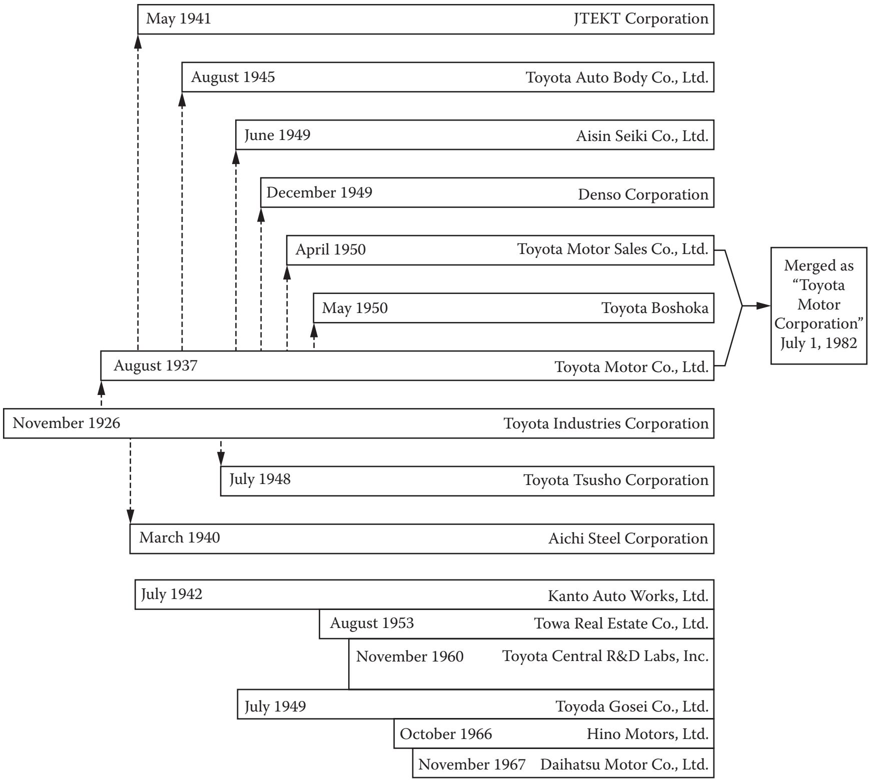
Mr. Taiichi Ohno, original developer of the Toyota Production System, says,

> In order to make the Toyota Production System truly effective, we should recognize its limitations. Only if Toyota shares its destiny with surrounding cooperative manufacturers as a single community can it approach the perfect realization of this system. Therefore, Toyota is improving the physical capabilities of our cooperative manufacturers by sending our I.E. staffs to them.

In short, paternal manufacturers must teach suppliers to implement the Toyota system, and at the same time the supplier must also frankly accept such guidance in order to make real improvements. With the existence of such a give-and-take relationship, warehouses are actually disappearing from the yards of Toyota's cooperative companies, including the second and third steps vendors.

It must be added, however, that it is somewhat difficult for a supplier to introduce a kanban system independently unless its paternal company dispatches the supplier kanban with smoothed order quantities.

Finally, another problem must be mentioned briefly: although there is no obvious resistance against the Toyota Production System among



Note: Dates for Hino Motors, Ltd. and Daihatsu Motor Co., Ltd. are for establishment of business partnerships with TMC. All others are for company establishment.

FIGURE 4.8
Formation of the Toyota Group.

Toyota's laborers, some people feel that this system will force the intensification of labor. At the present time it is difficult to justify such an argument with objective data. If we take into account the increasing number of suggestions per workers per year, we see that the humanity of laborers is well respected in this system. How Toyota has resolved the conflict between productivity and humanity will be discussed in Chapter 26. (Also see Muramatsu, Miyazaki, and Tanaka, 1980, 1981.) It is quite obvious that the Toyota Production System cannot be implemented in a company or organization where a labor union opposes productivity increases. This point may be the critical condition which will restrict the application of the Toyota Production System. Unless there is opposition from a labor union, this system can be applied to any company in any country.

§ 6 SUPPLIER KANBAN CIRCULATION IN THE PATERNAL MANUFACTURER

The production line is usually situated a short distance from material or parts storage, and in such situations the following steps will be taken to request supplier's materials or parts (each step number corresponds to the number in Figure 4.9):

1. When a worker at the production line sees a material box empty out, he will push the switch beside the line.
2. The material-calling andon located beside the material store will activate a lamp just under the metal plate indicating the material in question.
3. At the same time, a large red light will come on at the material storage.
4. The material carrier at the store will watch the material-calling andon to see which metal plate is lit.
5. Then, the carrier brings the box containing the material in question to the line. This box also contains the supplier kanban, but the carrier must detach it before he brings the box to the production line.
6. The supplier kanban will be brought to a post office for supplier kanban, where these kanban will be classified for each supplier in the same way as a post office will classify letters for each address.
7. The processed and classified supplier kanban will be given to the truck driver for subsequent delivery to the supplier. The empty boxes have already been loaded on the driver's truck.

The metal plate for each kind of material, which is part of the material-calling andon, is essentially a kind of *withdrawal* kanban. At the Aisin Seiki Company, Ltd., this metal plate is called kanban, and there is no kanban in the material boxes beside the production line. However, although the author once saw similar metal plates at the Honsha plant of Toyota, Toyota was calling this metal plate a "Coin" kanban. Each material box beside the line contains a standard supplier kanban.

The Honsha plant of Daihatsu Motor Company, Ltd., which has a business partnership with Toyota, is also using a plate-sliding file as depicted in Figure 4.10. In this plant, the metal plate, which a lamp has highlighted, will be placed in a plate-sliding file according to the order of its lamp's activation. Then, the carrier will withdraw the plate from the bottom of

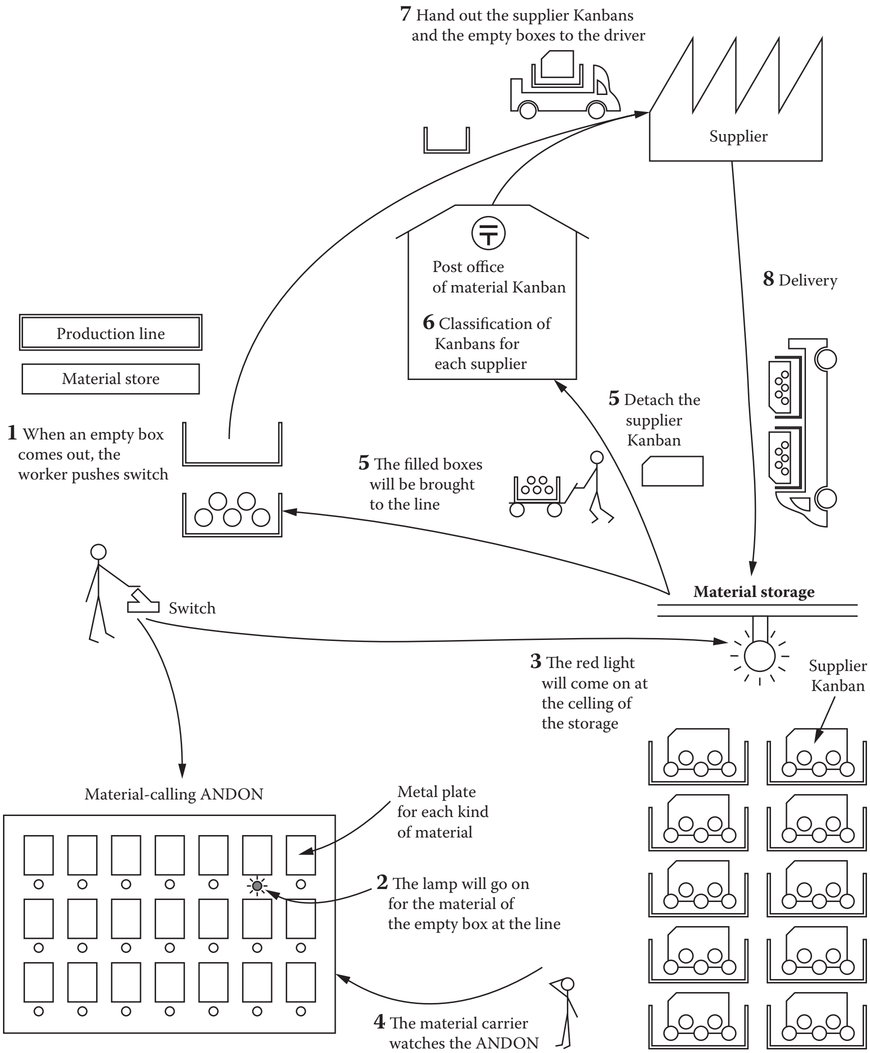


FIGURE 4.9
Material-calling andon for the later-replenishment system.

this sliding file, collect the materials designated by the plates from various stores in the plant, and bring them to the line. The material-calling andon or the metal-plate board has various forms in different companies. Each company devises its own forms. The details of the material-calling andon and metal plate will be explained as a *hired-taxi system* in Chapter 17.

The inside of the post office for supplier kanban is partially shown in Figure 4.11. The post office is located either beside or inside the material

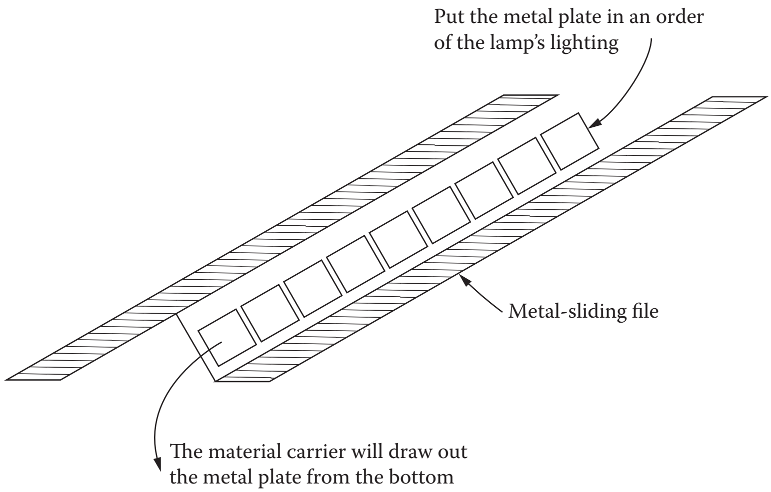


FIGURE 4.10
Metal plate sliding file.

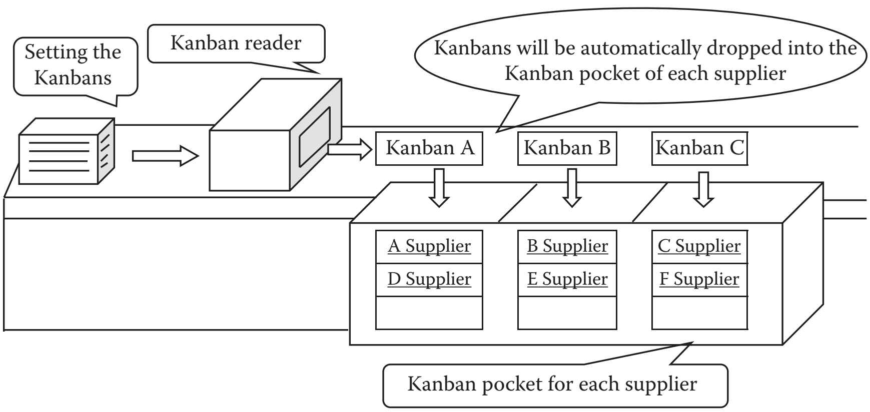


FIGURE 4.11
Post office for supplier kanban. (Adapted from Aoki, M. 2007. *Full Illustration of the Systems of Toyota Production Plants*, Nihon-Jitsugyou Shuppansha, p. 66.)

storage area. The supplier kanban detached at the manufacturing process and brought here will be introduced to the kanban sorter (also called the kanban reader), which automatically sorts the supplier kanban for each supplier. As the sorter reads the bar code on the kanban, that data can be transmitted simultaneously to the supplier electronically via EDI (electronic data interchange) based on the dedicated lines.

In this post office a staff member picks up the sorted kanban from each supplier's kanban pocket and puts it on the supplier kanban post beside this pocket.

Inventory Quantity of Purchased Parts

At a Daihatsu body-welding plant the inventory quantity of purchased parts that are supplied twice a day is the amount of one delivery unit plus the safety stock. The quantity of parts arriving five times a day equals one delivery, or one fifth of a daily supply, plus the safety inventory.

At Toyota Shatai, a car-body assembly plant, the delivery cycle is 1-10-6. This means that the inventory quantity equals a *one-time* delivery plus safety stock, a daily total of *ten* deliveries is made, and a delivery ordered by kanban is set off by a run *six* times after the kanban was dispatched to Toyota Shatai. Travel time from the body maker (located in Nagoya City) to the welding plant is three hours. Yet, trouble on the road sometimes causes the units already started and units in transit to arrive at the plant at one time. In such a case it is possible by phone to get Toyota Shatai to stop the next run, but it is impossible to stop the parts already on their way to the plant.

Generally speaking, the inventory for a quarter shift's use—that is, for two or three operations—is to be stocked according to the purchased parts. However, when increased production of a specified model is expected, or during a heavy snow season, the inventory is increased.

The number of kanban is adjusted monthly in accordance with the production volume for each month. If complications arise at the supplier's office resulting in a delay in supply, what should be done? Two common reasons for delay in supply are (1) misapplication of the kanban, and (2) trouble in the supplier facility.

The first case may need an explanation. A supplier located in the country is often small-sized and its production capacity may be insufficient to adapt to manufacturer demands conveyed via kanban. However, the forecasted requirements of each type of model are communicated three months in advance to the supplier from the plant on a rolling basis every month. Moreover, confirmations of the actual order are made twice in the month just previous to taking delivery. Therefore, the supplier should be able to avoid delay due to its limited capacity by producing and stocking the necessary inventory during previous months.

In contrast, if a supplier is located nearby, the maker may dispatch special carriers to the supplier or ask them to bring the parts quickly by taxi. Even if a supplier's plant is located in Nagoya City, small parts such as screw and bearings can be carried on a bullet train ("shin-kan sen train") and the maker (Daihatsu) has only to await its arrival at Shin-Osaka Station.

Incidentally, the deliveries from Nagoya District to the plant at Daihatsu are done at ten-minute intervals and seven or eight transportation firms are used. In addition, the maximum number of delivery runs from one particular supplier is 20 times a day.

§ 7 PRACTICAL EXAMPLES OF DELIVERY SYSTEM AND DELIVERY CYCLE

The Kyoto plant of Japan Glass Sheet Company, Ltd. has about 500 employees and produces about 600,000 to 700,000 square meters of glass monthly. The delivery to Toyota is made based on the kanban system; however, the kanban system is not used inside the plant. The characteristics of the kanban system in this plant are depicted in Figure 4.12.

Japan Sheet Glass Company, Ltd. contracts with a transportation firm to deliver kanban from Toyota. (In fact, this transportation company is one of many companies affiliated with Toyota.) Once delivered, the kanban are put into a kanban post divided into many sections for each supply run. In the plant's shipping area, products are stored for shipment and are separated by a kanban for each run. A kanban is then inserted into each pallet containing products, one kanban to a pallet. If the total number of pallets is different from the number of kanban, Toyota will have to hold excess stock. To avoid this problem, pallets are checked to ensure that the appropriate kanban are attached.

Number of Supply Runs and Delivery Schedule of Each Plant

Now let's describe the number of delivery runs to each Toyota plant. The Tsutsumi plant, for example, is supplied 16 times a day, and the units (glass) are unloaded at two places in the plant. The Motomachi plant is supplied 10 times a day at three places. Details for number of deliveries to each plant are shown in Figure 4.13.

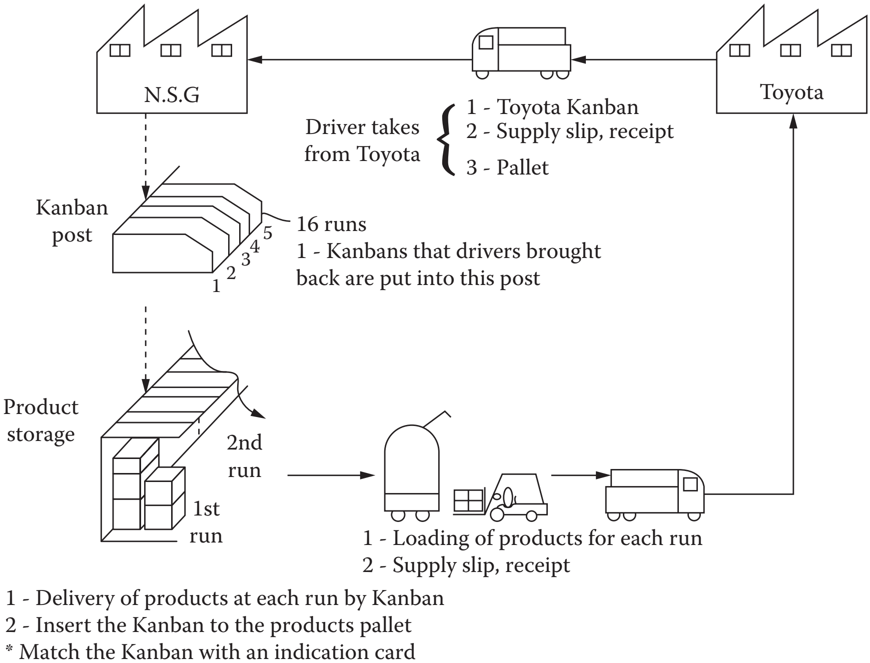


FIGURE 4.12
Circulation of supplier kanban.

Number of Runs to each Toyota Plant/Day

1	to	Tsutsumi plant	16 runs (2 places)
2	to	Motomachi plant	10 runs (3 places)
3	to	Takaoka plant	6 runs (3 places)
4	to	Tahara plant	4 runs (4 places)
5	to	Hino plant	3 runs (1 place)

FIGURE 4.13
Number of delivery times to each plant.

The total number of runs to each plant amounts to 39. If all of these runs were done individually, the transport cost would be compounded and quite expensive. Since an 11-ton truck is used for these deliveries, its capacity is more than one run. Therefore, a schedule of 20 runs total was devised. Destinations and runs were combined based on proximity, quantity, and load weight. The combination of destinations is shown in Figure 4.14.

This timetable is based on the 16 runs to Tsutsumi plant combined with runs to Motomachi plant and Takaoka plant. For example, the first run to

Number of deliveries to each plant				Departure from Japan Sheet Glass Co., Ltd.	Arrival at Toyota	Arrival time of Kanban	* Delivery cycle of each plant
Tsutsumi	Motomachi	Takaoka	Tahara				
1	1			3:20	8:00	13:30	1 - Tsutsumi plant 1 - 16 - 16
2	2			5:10	9:10	15:20	
3		1		4:10	8:20	14:20	
4	3			7:40	11:30	17:30	2 - Motomachi plant 1 - 10 - 10
5		2		7:20	11:20	17:30	
6	4			11:10	14:10	23:20	
7	5			12:20	15:50	24:30	3 - Takaoka plant 1 - 6 - 6
8		3		11:50	15:20	1:00	
9	6			14:20	21:00	2:30	
10	7			16:10	22:10	4:20	4 - Tahara plant 1 - 4 - 5
11		4		15:10	21:20	3:20	
12	8			18:30	24:30	6:50	
13		5		18:20	24:20	6:30	5 - Hino 1 - 2 - 4
14	9			24:10	3:40	10:20	
15	10			1:20	4:50	11:30	
16		6		1:50	4:20	11:00	
			1	21:00	7:50	7:00	
			2	5:00	12:50	15:00	
			3	10:00	20:50	20:00	
			4	16:00	1:50	4:00	

Note: This delivery schedule is based on the cycle to the Tsutsumi plant. Delivery to Motomachi and Takaoka are set within it and to Hino is relayed in Toyoda City then delivered by Toyota's run.

FIGURE 4.14
Delivery schedule for Toyota.

Tsutsumi is combined with the first run to Motomachi. Again, the second run to Tsutsumi is combined with the second run to Motomachi. Then, the third run is combined with the first run to Takaoka.

The four runs to the Tahara plant of Toyota are added to this timetable as independent runs because the plant is in an isolated location. Since the loaded quantity of the three runs to Hino Motorcycle Company is not very much, they are included in the 16 runs to Tsutsumi and are conveyed with the third, eighth, and eleventh runs to Tsutsumi.

The delivery cycle to each plant is written on the right side of this timetable. Although we have mentioned the delivery cycle before in Chapter 3 (see Figure 3.4), let's consider it again with actual examples. The former numbers 1 and 16 of the first two numbers in the delivery cycle for Tsutsumi plant (1-16-16) show that there are 16 delivery runs to Tsutsumi every day. The last number, 16, means that the delivery issued by a supplier kanban is actually carried out 16 runs after the supplier kanban arrives at the glass plant. In the case of the Tahara plant, the delivery cycle is 1-4-5. This means the delivery is four times a day, but the delivery is five runs after the kanban arrives.

The supply to Tsutsumi, instructed by a supplier kanban brought back to Toyota with the first run, is delivered by the next day's first run to Tsutsumi. The last number in the delivery cycle is determined by the distance between the Toyota plant and the supplier plant, rather than the production lead time of the supplier plant. In short, conveyance time is the chief cause. Therefore, a parts plant near Toyota could supply in a cycle of 1-16-4.

Kanban System and Adaptation to Emergency

How can the kanban system adapt to emergencies? The plant is 200 kilometers away from Toyota and it takes 3.5 hours one way by truck. If complications arise on the way, the JIT supply to Toyota becomes impossible and Toyota will be forced to stop operations. Take, for example, heavy snowfall in Sekigahara or traffic congestion on a national holiday. To deal with emergencies the plant has storage areas called "stations" 30 minutes away from the plant. In winter, inventory is stored in these storage areas for two days, and one day during other seasons. This is the safety inventory. Moreover, to avoid a delay in production, there is another storage area within the plant beside the shipping storage area for the exclusive use of kanban described previously. This holds stock for 0.6 months.

For the kanban system to be completely effective, conditions in the production process of suppliers are very important. Suppliers must be flexible and adapt to fluctuations in production when orders are given from Toyota. Machine breakdown, for example, must not occur in the supplier's plant. Unless the plant maintains a high actual operating rate, the kanban system does not work properly.

A strategy is necessary to deal with the problems of hazardous weather conditions and traffic conditions. Alternate driving routes have been established for these occurrences. Additionally, the plants have their own three-step process for assessing and dealing with delays and emergencies. They are:

Step 1—Caution: If less than a two-hour delay is expected, the trouble can be solved by consulting with the transportation company.
Step 2—Warning: If there is a delay of more than two hours, the plant itself takes action and thus plays a central role.
Step 3—Emergency: If there is a delay of more than three hours, emergency headquarters are established in this plant and the inventory in the "station" of the plant near Toyota is used.

Finally, when the kanban and units do not flow smoothly because of a problem within Toyota, although this is rare, the trouble is dealt with by adjusting the number of kanban from Toyota.

5

Smoothed Production Helps Toyota Adapt to Demand Changes and Reduce Inventory

The ultimate purpose of the Toyota Production System is to increase profit by reducing costs. Cost reduction is achieved by eliminating waste; waste is exposed and eliminated by just-in-time (JIT) production. In sales, the JIT concept will be realized by supplying salable products in salable quantities only. This situation is characterized as production that is promptly adaptable to demand changes. As a result, excess inventories of finished products can be eliminated.

At Toyota, the means for adapting production to variable demand is called *production smoothing*. The concept of production smoothing is to diminish as much as possible the quantity variance in a production line. The following sections highlight two phases of the production smoothing process—*smoothing of the total production quantity and smoothing of every model's production quantity*—for better understanding.

§ 1 SMOOTHING OF THE TOTAL PRODUCTION QUANTITY

Smoothing of the total production quantity is done to minimize the variance in total outputs between two sequential periods. In short, the goal of production smoothing is to produce the same amount of products every period (usually every day).

Although the demand for automobiles can change widely depending on the season thus affecting monthly production volumes, production smoothing allows daily production volumes to remain constant. For example, consider mass production of the Corolla. Initially, a per month quantitative production schedule is made, based on the demand forecast. This figure is then simply divided by the number of operating days in the month to get a daily production volume. In this manner, it may be feasible to develop a plan that would enable daily production of the desired number of cars. This is the *smoothing of the total production quantity.*

Using this concept, the priority is to maintain the daily production schedule for the Corolla model as a whole. Corolla models that vary from the basic model are not a consideration in this concept.

Another consideration is that the quantity of demand within a month is not constant. For example, demand for cars in the early part of a month may be high and then slack off during the latter part of the month. Under such a condition, if the same number of cars is produced every day, reserve inventories would be needed to provide enough cars to meet the demand early in the month, while excess inventories would accumulate at the end of the month because of the reduced demand for cars. Consequently, the shorter the period of a master production plan, the better for executing *smoothing of the total production quantity*; that is, a half-month plan is better than a monthly plan, while a weekly plan is even more desirable.

On the other hand, if the time span of the master production plan is too short, then smoothing of the total production quantity will disappear. In other words, if making a production plan according to actual orders that change daily, the function of smoothing of the total production quantity would produce just the averaged hourly production volume and would not level the total output in a month. Also, big fluctuations in the daily production volume force the plant to change its quantitative workforce every day, thus leading to waste of workforce especially at a plant where daily worker transfer is unfeasible. After all, smoothing of the total production quantity is meant to level the daily amount of products flowing as much as possible by anticipating peaks and valleys in demand. It is necessary for avoiding overall waste in an entire production system.

There are two kinds of waste. First, in plants where products are created in various quantities, the plant's facilities, people, inventories, and other elements necessary for production are prepared and set up for peak demand as the standard. As a result, during a period of short runs, the plant is likely to display waste in the forms of workforce and inventories, when compared with a peak period. This waste arises from *uneven periods of demand*.

The second type of waste occurs in processes (specifically final assembly lines) where the smoothing of the total production quantity has not been implemented yet and production occurs in a variant way. Since under the pull system a preceding process properly prepares its units in quantities corresponding to the peak quantity withdrawn by the subsequent process, it follows that excessive workforce and inventory build-up would occur. Here, the waste occurs *between processes*.

Variances in the total production quantity in a final assembly line at Toyota force related parts makers to retain excessive workforce and inventories because the pull system (kanban) connects processes at Toyota with external cooperative enterprises. To practice smoothing the total production quantity without occurrence of waste between processes, the final assembly line and all processes must produce products according to the cycle time. This means balancing between processes (synchronization) will be completely realized if every preceding process finishes at the same pace within the averaged cycle time for all specifications. The average cycle time for the whole operation is calculated by dividing the number of actual operating hours per day (480 minutes or 960 minutes) by the averaged daily production volume in the final assembly line. It is obvious from Figure 5.1 that the number of workers required corresponds to this cycle time. (Figure 5.1 shows the master production plan with two-week intervals at the motorbike plant of Kawasaki Heavy Industry.) In this figure, the worker transfer within a line is made every half month.

March												
Date	1	2	3	...	14	15	16	17	18	...	30	31
Production quantity	250	245	245	...	250	250	205	200	200	...	205	205
Total number of workers	54	54	54	...	54	54	44	44	44	...	44	44
Number of attendants	52	52	52	...	51	52	41	42	43	...	42	41
Line stop time (min.)	88	80	53	...	90	87	83	80	75	...	84	78
Cycle time (sec./unit)	120	120	120	...	121	121	140	144	144	...	140	140

FIGURE 5.1
Master production plan divided into two-week intervals.

Demand Fluctuation and Production Capacity Plan

The workforce layout in Figure 5.1 is for March, the month in which customer demand is at its peak. According to the schedule, the predetermined production volume per day from the first to the fifteenth of the month was 250 cars, while from the sixteenth to the thirty-first it was decreased to around 200. Therefore, 54 workers were assigned for the early part of the month and 44 were assigned for the latter part of the month. In the figure, 54 workers had been scheduled to work on March 2 but only 52 workers actually reported, causing the line to stop for 80 minutes that day. The line stop time is apt to increase proportionally to the number of absentees.

Adapting to Increased Demand

In the latter part of the month, each line is informed of the daily average quantity for the next month for each variety. This information and other planning data is calculated by a computer in the central production control department.

Once a production process receives its monthly schedule for average daily production, it must adapt its operations to the new information. For example, the load on a machine ordinarily is set at approximately 90 percent of its full capacity, and each worker, operating as a multi-function worker, might handle as many as ten machines. When demand increases, temporary workers are hired and each worker handles less than ten machines, thereby enabling 100 percent utilization of machine capacity. (It is, however, necessary to have machines on which even a newly hired, unskilled laborer will be able to become fully proficient within three days.) On assembly lines, for example, if a single worker has handled the job within a two-minute cycle time, he will be able to handle the same job within a one-minute cycle time when the number of temporary workers is increased. As a result, the production quantity can be doubled. This approach will also be applied to long-range plans for additional man and machine capacities.

Toyota can adapt to a relatively short-term increase in demand, by introducing early attendance and overtime, which can fill up unscheduled hours between the first shift (8 a.m.–5 p.m.) and the second shift (9 p.m.–6 a.m.). Doing so allows for an increase in production capacity of up to 37.5 percent (which is equal to 6 additional working hours/16 regular working hours). Moreover, various improvements within each process produce extra time that can be used during a period of increased demand.

Adapting to Decreased Demand

Adapting to decreased demand is considerably more difficult than adapting to an increase in demand. In parts manufacturing processes, the number of machines handled by each worker will increase, because temporary workers will be dismissed. On the assembly line, cycle time will increase due to the reduced demand quantity. How then should surplus manpower be utilized? Toyota believes that it is better to let extra workers take a rest than to produce unnecessary stock. The following are examples of activities that may be organized during a slack period:

- Transfer workers to other lines for which demand increased.
- Decrease overtime.
- Use a paid holiday.
- Conduct quality control circle meetings.
- Practice setup actions.
- Conduct maintenance and repair of machines.
- Manufacture improved tools and instruments.
- Conduct plant maintenance and upkeep.
- Manufacture parts previously purchased from suppliers.

Although the most important goal is improving the process to meet demands with a minimum number of workers, Toyota does not consider it necessary to minimize the number of machines. Their theory is to have the required machine capacity for peak demand and hire additional workers (temporary or seasonal) when needed so that effective production capacity can be easily expanded. Most Japanese manufacturing companies, including Toyota, employ many temporary workers.

§ 2 SMOOTHING EACH MODEL'S PRODUCTION QUANTITY

Smoothing a model's production quantity is an expansion on the idea of smoothing the total production quantity. Realizing that automobiles have thousands of specifications for various combinations of body types (i.e., sedans, hardtops, wagons, etc.), what would happen if the final assembly line produced one body type all day long? For example, consider the

	Monthly Output	Output per Shift	Cycle Time
A	9,600 units	240 units	2' = 480/240
B	4,800 units	120 units	4' = 480/120
C	2,400 units	60 units	8' = 480/60
	16,800 units/months	420 units/shift	1.14' = 480 min/420 units

FIGURE 5.2
Smoothing of each model's production quantity and cycle time.

efficiency of a final assembly line that produces sedans one day, hardtops the next, and vans the day after that. A preceding process making the parts for sedans would have work to do one day, but not again for two days. The same would be true of the lines dedicated to vans and hardtops. However, if every subassembly line completed its full production capacity of all types of stock every day with no stoppage of operations, the quantity of finished parts would be very large—about three or four times the quantity produced by smoothed production. The waste of overproduction in preceding processes or subassemblies is considerable. It becomes apparent then that smoothing of every model's production quantity is required.

Suppose 16,800 Corollas must be produced in a month that has 20 operating days. Ninety-six hundred sedans (A), 4800 hardtops (B), and 2,400 wagons (C) are needed. Under a two-shift operation per day, each shift will have to produce 240 sedans, 120 hardtops, and 60 wagons per day. (See Figure 5.2.) Here, the cycle time is determined by dividing 480 minutes by the production volume per shift. According to this calculation, one product A has to be produced in 2 minutes and one product B in 4 minutes. Thus, on average, one car of any type must be produced in 1.14 minutes.

In short, the purpose of smoothing every model's production quantity is to check variances in the flow of each product variety between periods (days). The aim is to level the quantity of parts consumed and produced each period because if great variances existed in the daily consumed quantity of parts of a specified variety, the subassembly lines in question would have to hold huge excess inventories and workforce.

Sequence Schedule for Introducing Models

All product varieties can be produced according to the average cycle time of all varieties as long as each model's cycle time is considered when

FIGURE 5.3
Sequence scheduling smoothed production.

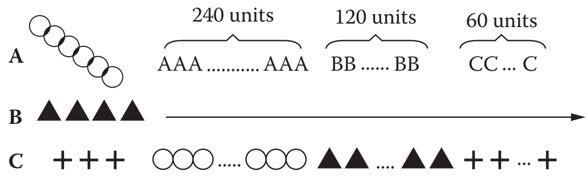


FIGURE 5.4
Lot (batch) production.

determining the sequence of each model. Figure 5.3 depicts sequence scheduling for the smoothed production of Toyota.

Figure 5.4 illustrates lot (batch) production in which production occurs at the line's own peculiar speed, rather than at the speed dictated by market demand. This type of production can cause variances in the necessary volumes of each subassembly part. However, even by using lot production, many companies are able to achieve smoothing of production by using a daily production quantity. This is true in plants where the required number of products is conveyed to the retail store once a day as is the delivery of necessary parts to the company. As a result, the amount of parts to be supplied does not change much. Companies that employ lot production will probably never achieve the ultimate in smoothed production—responding to sales velocity of each product sold in the marketplace. To illustrate this point, consider the following example.

Assuming that the lot production method is being used, suppose a plant introduces the kanban system and forces its cooperative makers to deliver the necessary parts hourly. Parts makers will suffer from large variances in quantity withdrawn each hour. Unless the quantity becomes constant, the parts makers must prepare extra stock to adapt to the hourly order.

At Toyota, the concept of smoothed production is also applied to the difference in man-hours it takes to produce different cars on the same line. Toyota classifies the various cars on a production line by man-hours required for each type of product into three groups: large, medium, and

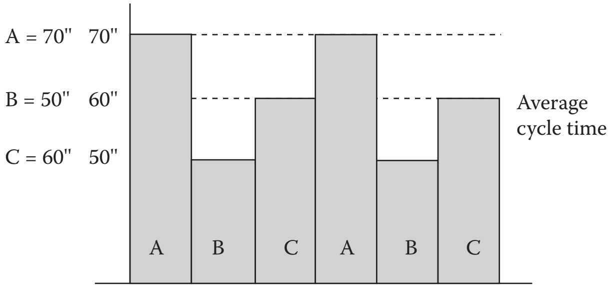


FIGURE 5.5
Sequence schedule that enables assembly within the average cycle time.

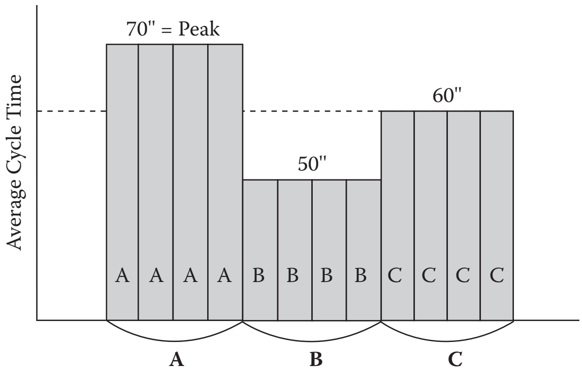


FIGURE 5.6
Sequence schedule that causes line stoppage.

small. Each of these groups is further identified by a specific color: red, white, or yellow.

Suppose the man-hours needed to produce A, B, and C on the same line are 70 minutes, 50 minutes, and 60 minutes, respectively. If the cars are produced in a certain sequence, i.e., A, B, C, A, B, C, the line would not stop because the average cycle time of this line is 60 minutes. See Figure 5.5. However, if product A (Figure 5.6) is lot-produced, this 60-minute cycle time line will not be able to complete it because A needs a 70-minute cycle time. This would cause the line to stop. In order to prevent the line from stopping, the number of workers would have to be increased to complete the work within 70 minutes, the peak operation cycle time.

Man-hours can also be smoothed in the same way as is the sequence of vehicles. This point will be explained further in the goal chasing method described in Chapter 20.

Incidentally, what has brought about the smoothing of each model's production quantity is a tendency to produce vehicles corresponding to the diversification of needs in the marketplace. In other words, if the market had not demanded such diversification, smoothing of the total production quantity alone would have satisfied demand changes. Nevertheless, as the diverse specifications production increases, realizing the smoothing of each model's production quantity becomes more difficult.

First of all, as the number of diverse models increases, the number of lots also increases as do setup actions for each preceding process. Conversely, if decreases in frequent setups at preceding processes are desired, the lot sizes would have to be increased at each preceding process and considerable stockpiles of parts inventory would result.

Sequence Schedule Sheet Sample

Typically, automobile assembly lines are characterized as mixed-model assembly lines where different car models are manufactured. As an example, we shall examine a motorbike assembly line at Kawasaki Heavy Industries.

In this assembly line, different types of motorbikes are assembled on the line in a mixed order. The same type of motorbike is manufactured successively in lots of five units instead of the ideal lot size of one. All parts required for the production of five motorbikes are ordered as one lot.

This plant has four main assembly lines and assembles 50 models. The length of assembly time required for each model is different. If assembly times for two sequential models differ greatly, they are simply produced nonsequentially, and a few models from the former five motorbikes are inserted into the production mix to take up slack time. Figure 5.7 shows the actual production sequence for the F-3 assembly line.

Sequenced Withdrawal of Engines

Final assembly is achieved in the following manner at Toyota's Takaoka factory. Trucks bring 12 engines at a time to the plant in regular intervals of ten to fifteen minutes. This process ensures almost zero inventory. The engines are unloaded and fitted with transaccelerators, transmissions, and so on, before being put in line for assembly with the car body. This sequenced withdrawal system is based on the *constant-quantity and inconstant-cycle* principle.

F3 Line Production Instruction Sheet				
Date	Kawasaki Heavy Ind. (motorcycle) Manufacturing Department			
Sequence	**Model**	**Spec.**	**Color**	**Lot size**
16-001	ZX 400D	C 101	BLK	5
16-002	ZX 400F	A 101	BLK	5
16-003	ZX 600C	A 402	RED	5
16-004	ZX 400D	C 101	BLK	5
16-005	ZX 600C	A 201	RED	5
16-006	KZ 750P	E 405	RED	5
16-007	ZX 400D	C 101	BLK	5
16-008	ZX 400F	A 101	BLK	5
16-009	ZLT 00A	A 303	BLU	5
16-010	ZX 400D	C 101	BLK	5
16-011	ZX 600C	A 201	RED	5
16-012	ZX 600c	A 402	RED	5
16-013	ZX 400D	C 101	BLK	5
16-014	KX 600A	C 402	BLK	5
16-015	ZX 400D	C 101	BLK	5
16-016	ZX 600C	A 402	WHT	5
16-017	ZX 400F	A 101	BLK	5
16-018	ZX 400D	C 101	BLK	5
16-019	ZX 550A	D 405	BLK	5
16-020	ZX 600C	A 201	RED	5
16-021	KZ 400D	C 101	BLK	5
16-022	ZX 600A	D 401	BLU	5
16-023	ZX 600A	C 402	BLK	5

FIGURE 5.7
Sequence instruction sheet for F3 assembly line.

The engine factory has produced engines according to a production schedule corresponding to car body production because the final assembly begins only two hours after the car body is painted. If the assembly plant issues the production order to the engine factory after the painting process, the required engines cannot be supplied in time. If this happens, a small inventory of additional engines is usually stored so adjustments can be made.

The production sequence in the final assembly line is: accelerator pedal, heater, ceiling, instrument panel, quarter glass, rear glass, wiring, gas tank, engine, and tires. Cars are suspended on the chassis assembly line for attachment of suspension systems, brakes, and exhaust systems. After the door handles and wipers have been attached, assembly work is complete and detection and adjustments are performed on each car.

Two Phases of Production Smoothing

Figure 5.8 shows the analysis of the two phases of production smoothing. The first phase shows the adaptation to monthly demand changes during a year (monthly adaptation), and the second phase shows adaptation to daily demand changes during a month (daily adaptation). The first phase, monthly adaptation, will be achieved by monthly production planning—the preparation of a master production schedule instructing the averaged daily production level of each process in the plant. This master production schedule is based on a monthly demand forecast.

The next phase, daily adaptation, is made possible by daily production dispatching. Here, the role of the kanban system is needed for production smoothing because daily production dispatching can only be achieved by using a pulling system. The kanban system and sequence schedule provide that system. Only when a sequence schedule is prepared for the mixed-model assembly line can Toyota make smoothed withdrawals from its suppliers and subassemblies.

Details of an information system concerning the monthly production schedule and determining daily production dispatching will be described in Chapter 6.

Flexible Machinery Supporting Smoothed Production

Since production smoothing requires production of many varieties of products on the same line each day, it necessarily gets more complicated and difficult to achieve as variety is promoted in the marketplace. Fortunately, Toyota has developed facilities to resolve the conflict between market variety and the ideal of production smoothing, i.e., multi-function machines in the line. The exclusive-purpose machine is a powerful means of reducing mass-production costs, but it is not suitable for varied

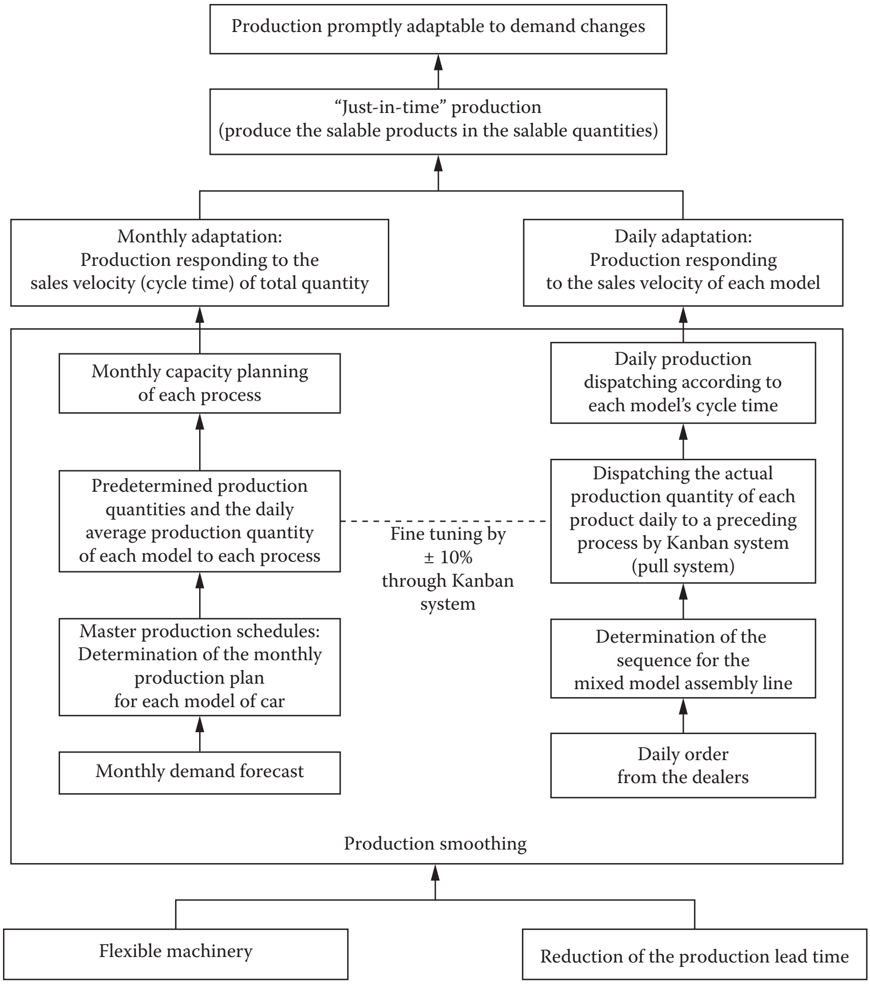


FIGURE 5.8
Framework of Toyota's production smoothing.

short-run productions. Thus, it is necessary to add minimal apparatus and tools to such exclusive machines, turning them into the type of multi-purpose machines required in Toyota plants.

Another mechanical means for supporting the smoothing of production is the flexible manufacturing system (FMS). Narrowly defined, FMS is an automatic production system consisting of an automatic machining instrument, an automatic conveyance instrument, a material handling instrument, and a microcomputer system which controls these instruments. The FMS's function is to automatically control alteration in specifications, machining time, lot size, etc. by using the production schedule program memorized in the microcomputer.

Introduction of FMS enables a factory to respond to many varieties and short-run productions by means of hardware. However, such progress in hardware can sometimes require significant investment in facilities to support production. In such cases, the system may create some problems for medium and small manufacturers.

§ 3 COMPARISON OF THE KANBAN SYSTEM WITH MRP

From the viewpoint of adapting production to demand changes during a month, material requirement planning (MRP) and the kanban system both aim to realize JIT production. MRP is a system that uses bills of material, inventory, open order data, lead time, and master production schedules to calculate requirements for materials.

For the MRP technique, the concept of a *time bucket* is very important. A time bucket is a specifically allotted period of time in which a certain quantity of units must be produced. In a sense, the time bucket concept can be seen in the kanban system in one day; yet a typical MRP *time bucket* will entail at least a week. Furthermore, MRP necessitates the *time phasing* concept, which requires making up an inter-bucket schedule that dispatches parts to a product by using lead time data.

The kanban system does not essentially require this time-phasing concept since it is based on smoothed production. However, the delivery cycle must often be considered in determining the number of kanban based on the lead time of the production process. (Refer to Figure 3.4 and Chapter 22.) In the case of very short production runs where smoothing of production is very difficult, MRP may be more appropriate.

As seen in Figure 5.8, the kanban system requires that an overall production schedule be circulated throughout the plant before actual production begins. Such an overall plan in MRP is called a *master schedule*. This master schedule is very important for MRP because it is a target to be rigorously maintained. In the kanban system, the overall plan does not strictly target production, but merely sets up a loose framework that prepares the plant-wide arrangement of materials and workers at each process.

Consequently, in the MRP system, a review must be made at the end of every planned production interval—or bucket—that compares planned production with actual performance. If the review discovers a discrepancy between planned and actual performances, remedial action must be taken. Since these are bucket sizes of at least a week, the master schedule must be revised weekly.

The kanban system does not require any comparisons between planned and actual performance at the end of a production interval, i.e., one day, because such comparisons must necessarily evolve out of the daily actual production process and the daily dispatching of production by kanban. If the daily production plan—the sequence schedule—requires revision, such revision will be based on the dealer's daily orders and will reflect daily market conditions. Furthermore, since the kanban actually flow backward through the plant from the final assembly line to the preceding process, only the final assembly line needs to be notified of any changes in sequence for the entire plant's production to be modified autonomously and in a decentralized way within every process. Hence, the kanban system is characterized as a *pull system*, while other means of dispatching production information, such as MRP, are characterized as *push systems*, where the push comes from a central planning office.

However, the kanban system can be compatible with MRP. After MRP creates the master schedule, the kanban system could be applied as a dispatching tool of production within each bucket. Yamaha Motor Company, Ltd. is employing this system which they have named Pan Yamaha Manufacturing Control (PYMAC).

§ 4 SUMMARY OF THE CONCEPT OF PRODUCTION SMOOTHING

Generally speaking, production smoothing serves to minimize variance in production quantities. Strictly speaking, however, there exist four concepts of production smoothing corresponding to the following subgoals of just-in-time:

(a) Subgoal 1 is to minimize variance in the usage of parts and/or materials constituting the final products. That is called *parts usage smoothing.* This is the most important goal among the four smoothing goals for the purpose of implementing a kanban "pull system."

(b) The assembly time varies for the different products flowing on the final assembly line. If a certain product requiring a longer assembly time is continuously introduced to the line, the line will stop. To prevent such a situation, products with varied assembly times must be introduced with even variance into the line. This is called *product work-load smoothing.*

(c) Another subgoal is to produce daily as many units of product as can be sold on average day in the month in question. For example, if 200 units of product A are estimated to be sold in the next month and there are 20 operating days that month, then an average of 20 units per day (200 units / 20 days) must be produced consistently each day during the next month. In other words, each product must be produced in accordance with its takt time. As a result, excess inventory of finished products in the sales market will be minimized. This is *product sales-rate smoothing.*

(d) As with product work-load smoothing, the parts assembly line (or subassembly line) that directly links to the final product assembly line also makes a variety of parts, and these parts must in turn flow smoothly, to prevent products requiring a longer assembly time to flow in succession. This is also for the purpose of avoiding line stoppage and is called *parts work-load smoothing.* However, this type of smoothing is essentially the same as product work-load smoothing (b), so we can consider that there are basically three types of smoothing concepts.

What relationships can be seen among the three main smoothing concepts of (a) parts usage smoothing, (b) product work-load smoothing, and (c) product sales-rate smoothing? A positive correlation exists between (a) and (c). This has been verified by the simulation experiment of Aigbedo and Monden (1996). However, conflict will often occur between (a) and (b), requiring some coordination.

To achieve any of the four goals of smoothing, the central problem for us is how to determine the *sequence schedule of the mixed model assembly line*. For achieving the above four goals at the same time, we need some method of multi-goal sequence scheduling, on which various research efforts have been conducted. Two methods are being utilized in practice: One is the *Goal Chasing Method,* which makes a composite objective function for goals (a) and (b). The second is the *Goal Coordination Method,* which utilizes an artificial intelligence (AI) approach together with the goal chasing method. These two methods will be explained in detail in Chapters 20 and 21, respectively.

6

The Information System for Supply Chain Management between Toyota, Its Dealers, and Parts Manufacturers

In this chapter, the information system that links Toyota to its dealers and parts manufacturers will be examined. The first topic is how dealers transmit sales data to Toyota and how Toyota processes this data. How Toyota informs its suppliers of the parts and materials needed to produce specific vehicles will be discussed next, followed by a description of Toyota's new Toyota Network System (TNS), and lastly, a description of the information system within Nissan Motor Company, which is a rival car manufacturer of Toyota.

§ 1 THE ORDER ENTRY INFORMATION SYSTEM

Toyota plans its production in two steps. The first step is preparing a monthly production plan, which consists of a *master production schedule* and a *parts requirement forecast* table. The second step is developing a daily production order after deciding the product delivery schedule and the sequenced schedule of production.

Monthly Production System

Master Production Schedule and Parts Requirement Forecast

To make the master production schedule and the parts requirement forecast, managers create a monthly sales plan. Both domestic and foreign sales departments are involved in this planning. Every month, the domestic sales department receives information estimating the demand for the following three months. The estimates are listed according to models (car model lines) and major specifications. The major model specifications are determined by the combination of different body types, engine sizes, transmission types, grades of models, and so on. The foreign sales department also receives estimated demand data from its foreign dealers in the same manner as the domestic sales department.

In addition to this sales data, Toyota's managers take into consideration the production capacity of their plants when developing the production plan. First, production smoothing is planned for the most recent month (dividing the total number of cars for each model line by the total number of working days in a month). This is called the *master production schedule*.

The Material Requirement Plan (MRP) is then prepared based on the master production schedule, using a bill of materials. This method is used by all car manufacturers whether they call this process MRP or not. Required materials and parts calculated by MRP are then sent to each Toyota plant and each subcontract parts manufacturer. This is the *parts requirement forecast*. However, as will be discussed later in this chapter, each parts manufacturer is not required to follow this parts requirement forecast for their daily production. Variations in the production order are reflected through Toyota's kanban system.

Daily Production System

The Product Delivery Schedule and Sequence Schedule

Toyota's daily production schedule is determined by the product delivery schedule and the sequence schedule. Daily production information is sent from dealers and processed as follows:

1. A 10-day order is sent to Toyota's sales division from dealers.
2. A daily order (daily alteration if necessary) is sent to Toyota's sales division from dealers.
3. Toyota's sales division sends the daily order to Toyota's manufacturing division.
4. A daily sequenced production schedule is created and sent to Toyota's plants and suppliers.

These four steps are described in detail below.

Step 1. Each dealer sends Toyota's sales division the 10-day order specifications for each model as ordered by customers, including color and option preferences. The accumulated quantity of three days of the 10-day order cannot exceed the production volume determined by the monthly master production schedule. This 10-day order is sent by computer seven to eight days before the beginning of each 10-day order period (see Figure 6.1). Then, based on the 10-day order, the daily production quantity for each line and each plant is planned. This means modification of the master production schedule and an update to the delivery schedule as shown in Figure 6.2.

Step 2. Statistically, Toyota can expect changes to the 10-day order to be in the plus or minus 10 percent range (maximum 23 percent). For example, as Figure 6.2 shows, when receiving the actual order for a white car instead of a red car, Toyota must change its production

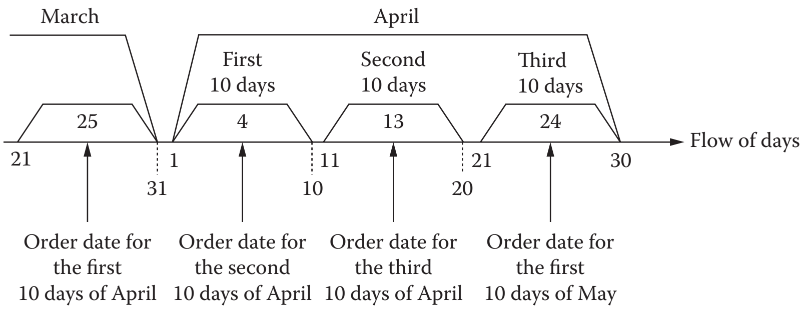


FIGURE 6.1
10-day order from the dealer.

Order number \ Month and day	June									
	1	2	3	4	5	6	7	8	9	10
XXX (White)	●					•				
XXX (Red)			●					•		
XXX					●				•	

FIGURE 6.2
Delivery schedule.

and delivery schedules from producing a red car to a white car. This process is called *daily alteration* and is done four days before the roll-off of the final product from the assembly line.

Step 3. Toyota sales division's computer system divides dealer orders into categories for different types of models, bodies, engine sizes, transmissions, body colors, etc. The sales division then sends this information to the manufacturing division three days before the roll-off of the final product. It is very important for the manufacturing division to receive this information so that required daily production can be determined.

Step 4. After receiving the daily orders from Toyota's sales division, the manufacturing division prepares the sequenced production schedule for the mixed model assembly line. The final assembly line is informed of the sequenced production schedule only two days before the roll-off of the final product. It should be noted that this sequenced schedule is revised and sent to the assembly line every day. Figure 6.3 illustrates the flow of the order and production information from step 2 to step 4.

The four-step ordering process allows the final product to be rolled off the assembly line just four days after dealers send in their orders. To further facilitate speedy production, Toyota limits the actual production lead time between the welding line and the final assembly line to one day. On the other hand, delivery and shipping lead times vary because of differences in the geographical locations of dealers.

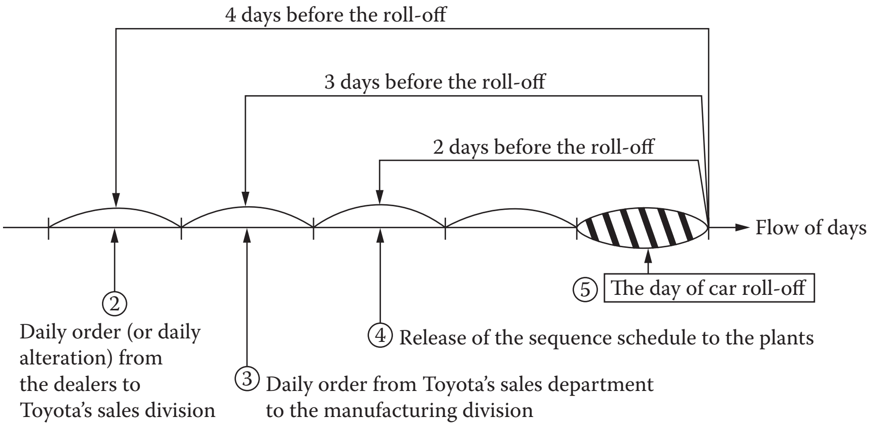


FIGURE 6.3
Steps from dealer's daily order to the car roll-off.

The Sequenced Production Schedule

All workers in the final assembly line only need to know what kind of car they are to assemble. To obtain this information, computer printers and displays are installed at the final assembly line. The sequenced production schedule determines the order of models to be assembled and is sent from the central computer to the printers and displays in an online real-time manner. Printers are used for the sequenced production schedule because printed documents are needed at the final assembly line. In other assembly functions where a written document is not needed, only displays are used.

In addition to this information, the computer terminals provide specification labels, which are attached to the car body. Each worker in the final assembly line can build the exact specification of each model demanded by using parts described on the label. Other parts assembly lines and suppliers who produce large unit parts, such as engines or transmissions, also use the label and sequenced production schedule to facilitate sequenced withdrawal of parts. The remaining lines, such as the casting line, machining line, etc., as well as suppliers, use kanban (*later replenishment system*) to control their production quantities.

Online System at the Distribution Stage

For the automobile manufacturer, reduction of the overall lead time—from reception of customer orders at the dealer to the distribution of a car to the customer—is crucial to meet the customer's satisfaction. This is partially done by reducing the dealer order processing time.

Before Toyota installed a computer system, dealers sent both 10-day orders and daily alterations to Toyota by telex. With this system, it took at least three weeks, and sometimes as much as two months, for dealers to receive the cars they ordered.

Toyota developed its current online system which enables it to reduce the ordering process and promptly respond to customers' demands. Toyota's dealer network system uses a new fiber optic cable route that was installed throughout Japan by Japan's leading domestic phone company, NTT. This system links the mainframe of Toyota's head office and Nagoya branch office (Toyota's sales division) with terminals at every dealership. Initially, this network system was installed only among the four major Japanese Toyota sales companies (Tokyo Toyopet, Osaka Toyopet, Aichi Toyota Motor, and Kanagawa Toyota Motors). In January 1968, when

Toyota began to produce its luxury car, “Crown,” it initiated an ordering process using the online system, and gradually expanded this system throughout the country.

This system has three types of functions: real-time processing, file transmission, and electronic mailing. To utilize these functions at dealerships that had different computer systems, Toyota developed and installed a business protocol at each dealer which allowed for Open System Interconnection (OSI).

Using the network system, Toyota was able to improve its operations in many areas. First, Toyota now knows inventory information at all dealers, and dealers can move stock to other dealers as required. Second, Toyota can apply a flexible delivery schedule in that it can quickly change the delivery destination as required. For example, automobiles to be shipped to dealer A can easily be shipped to dealer B instead. Third, Toyota can inform the dealers which model is in high demand and which model is not. By providing this information, Toyota can advise dealers of their purchase plan. This procedure is similar to a point of sale (POS) system, which is used in supermarkets and department stores. The C90 office at Toyota was in charge of communication between dealers and Toyota.

§ 2 THE INFORMATION SYSTEM BETWEEN TOYOTA AND PARTS MANUFACTURERS

Parts Requirement Forecast Table

Toyota sends a three-month production schedule, called a *parts requirement forecast table*, to its parts suppliers. Information about actual parts supplied during the most recent month is provided as a final forecast and recorded on a daily basis. The forecast for the remaining two months is estimated.

In all likelihood, these estimates will change from day-to-day. Additionally, the actual production volume is sometimes increased or decreased from the volume depicted in the forecast table. These adjustments to the production forecast are made via the kanban system as a fine-tuning measure.

The quantity of different parts to be supplied is projected in the parts requirement forecast table shown in Figure 6.4. (Figure 6.4 does not show the two-month forecast because of space limitations.)

To supplier XXXX

PARTS REQUIREMENT FORECAST (FOR MAY)

Prepared April 22, 1992

Parts	Delivery Cycle			Number of Kanban	Difference with the Former Time	Number of part box per day (10 units/box)												Requirement Forecast for May
	day	times	later			Day 1	2	3	~	6	7	Day 8	~	29	30	Day 31		
A	1	14	3	4	−1	8	8	0		8	8	8		8	8	8		1,718
B	1	14	3	3	0	6	5	0		5	5	5		5	5	4		1,020
C	1	10	2	3	−1	7	7	0		7	7	7		7	7	7		1,600
D	1	14	2	19	3	44	44	0		45	44	44		44	44	44		9,761
E	1	14	3	2	−1	5	5	0		5	5	5		5	5	5		1,141
F	1	10	2	1	0	1	0	0		0	0	1		1	0	0		94

FIGURE 6.4
Parts requirement forecast table.

As a specific example, the instructions for part C follow:

- Estimated quantities.
  - Total quantity to be withdrawn in May = 1,600
  - Total quantity to be withdrawn in June = 1,600*
  - Total quantity to be withdrawn in July = 1,700*
    - Forecasted quantities for June and July are not shown. The total quantity to be withdrawn in May is a finally determined number provided the adjustment by the kanban system during the current production is excluded.
- Parts per box. Each box contains ten parts.
- Quantity of boxes per day. The number of boxes to be supplied daily in May is indicated. Note that in May the supplier's daily production of part C is a smoothed (constant) number of boxes per day, where

$$\frac{\text{Total number withdrawn in May} = 1{,}600}{\text{The number of parts / box} = 10} \times \frac{1}{\text{Total working days} = 22}$$

$$= 7 \text{ boxes per day}$$

- Kanban information:
  - Delivery frequency of kanban. Kanban are delivered ten times a day, and finished parts should be delivered to Toyota two delivery times after the supplier has received the kanban. Therefore, the delivery cycle of parts C is 1-10-2.
  - Number of kanban. This specifies the total number of kanban used for the part by Toyota. For item C, three kanban are used.
- Differences with the former time. For part C, kanban are delivered every other delivery time. A difference of "-1" means that at delivery time *t*, the parts corresponding to two kanban are supplied. But at point in time *t*+2, parts corresponding to only one kanban are supplied (see Figure 6.5).

Network System within Toyota Group Using VAN

Using VAN, a "Value-Added Network" system has been built between Toyota and the major suppliers in the Toyota group, such as Nippon Denso, Toyota Fabric, and Toyota Automatic Loom Works. This network is called TNS-S. Recently, Toyota built an online network to communicate with

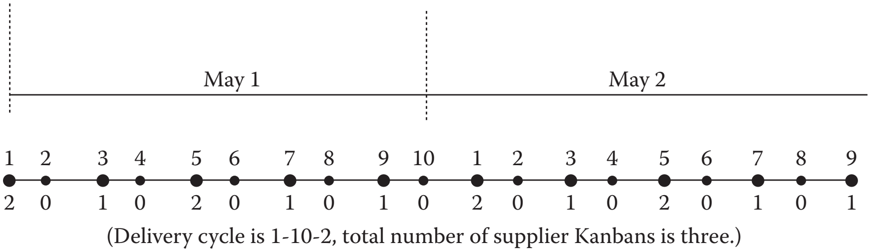


FIGURE 6.5
Delivery cycle and number of kanban per delivery.

outside contract automobile body makers, such as Toyota Body, Kanto Auto, and Daihatsu Motor.

The communication link within Toyota groups using VAN allows the parts requirement forecast table and the sequenced production schedule to be sent through the computer system. In addition, Toyota's assembly plants can send the sequenced production schedule to in-house engine plants through a telecommunications line.

The system also solved the problem that outside body makers had because they were unable to send timely information through the old computer system to a parts maker who was also a Toyota contractor. The system allows Toyota and the outside body maker to send parts requirement information simultaneously to parts manufacturers.

The Parts Distribution System

This communication network is actually Toyota's Strategic Information System (SIS), also called the Toyota Network System (TNS), and consists of the following six subsystems:

1. TNS-D—Network between Toyota and dealers.
2. TNS-B—Network between Toyota and body makers.
3. TNS-S—Network between Toyota and suppliers.
4. New ALC system—The New Assembly Line Control System which is a portion of Toyota's in-house CIM.
5. Information System at sales companies.
6. TNS-O—Network between Toyota and overseas plants and dealers.

By having this information network, Toyota can adapt to the market demand very quickly as a whole synchronous organization whose members are the automaker (Toyota), dealers (domestic and overseas), suppliers and body makers, and so on. In other words, Toyota can respond to changes in market demands (in terms of preferences of customers, products, variety, and quantity, etc.) in each stage of development—sales, manufacturing, and parts purchasing.

Additionally, a transportation company opened a warehouse between Toyota and its parts suppliers. This warehouse functions as a distribution center, and every part demanded by kanban is distributed from its stock on an hourly basis. The inventory in this distribution center is only for one to two days' consumption. It is important to mention that the warehouse stores parts from various parts suppliers. The warehouse functions like a dam, where water from various small streams (parts makers) is pooled for one to two days' consumption, and then poured as a mixed load into one big stream (Toyota) on an hourly basis. Figure 6.6 depicts the whole information network system among Toyota, its dealers, parts manufacturers, body makers, and so on.

§ 3 NEW TOYOTA NETWORK SYSTEM (TNS)

Establishment of Type II Carrier by Toyota

With Toyota's old TNS, information transmission between Toyota and each of the Toyota Group companies was on a one-to-one basis. The construction of this type of system was permitted by law, whereas, as a manufacturing company, Toyota was not permitted to build an N-to-N type network allowing its group companies to communicate with Toyota itself and with each other.

To begin with, the only type of company allowed to install fiber optic cables and other communications lines themselves at that time were "Type I Carriers" such as NTT, KDD, DDI and ITJ, while the only type of company allowed to provide VANs (Value-Added Networks, which use networks to provide hard/soft information system sharing and data sharing/transmission) were so-called "Type II Carriers." These companies leased lines from Type I Carriers to provide value-added services, and were limited to a few such as NTT Data Transmission, and Recruit.

Toyota therefore decided to set up its own Type II Carrier company. In doing so, it was able to receive help in seconding staff and raising capital

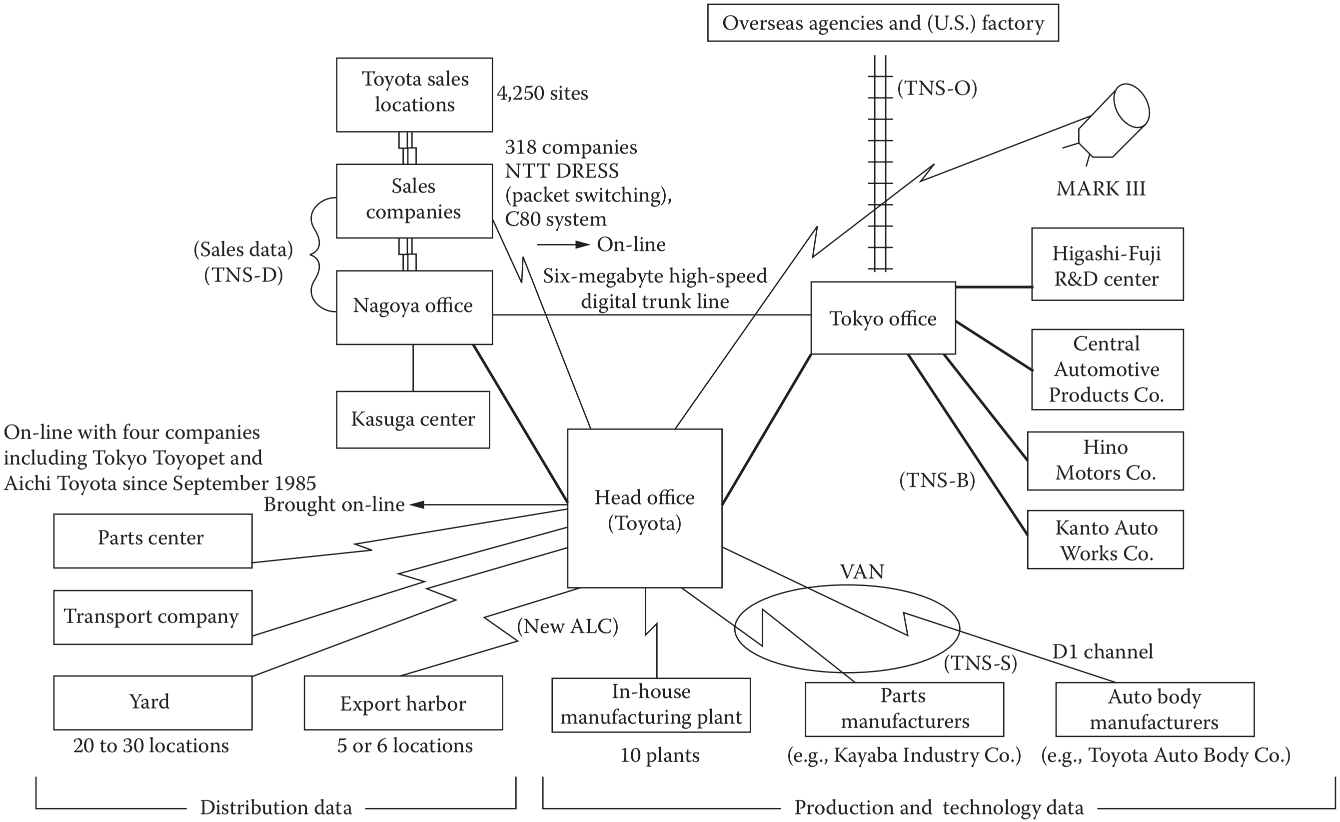


FIGURE 6.6
Strategic Information System (SIS) of Toyota.

from leading suppliers within the Toyota Group and from information device and computer manufacturers with which it had enjoyed close relationships.

The Type II Carrier company Toyota Digital Cruise (TDC) was established in this way at the end of March 1996. As explained below, this company later led the way in setting up the Toyota Group's new TNS.

Toyota's New TNS (Toyota Network System)

Toyota's TNS network system was introduced in 1989 and went live at the beginning of the 1990s, enabling Toyota Group companies to exchange electronic data with each other via the network. However, the bottleneck in the system was the lack of commonality, since automobile companies in Japan and overseas all used their own unique systems (formats, etc.).

This led to the emergence of two separate moves to create a global standard; one was CALS (Computer-Aided Acquisition and Logistic Support) and the other was EDI (Electronic Data Interchange). CALS originated in the U.S. Defense Department's BPR (Business Process Re-Engineering) program and is now a system of standardization for business transaction practices, as implied by its name (Commerce at Light Speed), while EDI is an agreement for standardizing the communications protocols and formats of accounting data for commercial transactions for work such as settling accounts between different companies. Organizations such as JAMA (Japan Automotive Manufacturers' Association) and JAPIA (Japan Auto Part Industries' Association) took the lead in promoting integration within these systems, and Toyota was also involved.

The Internet began to take off at around the middle of the 1990s, and business entered the age of electronic commerce (EC) conducted by means of extranets linking different companies.

At Toyota, TDC developed a Toyota Group intranet, called D-Cruise Net, and the new TNS, Toyota's B to B (Business to Business) system, was constructed by means of this. Although called an intranet, Toyota Group's intranet is actually what is usually called an inter-company extranet. Figure 6.7 shows an outline of the new TNS. It is faster than the old network, can handle larger files, and is able to transmit the data for both documents and drawings.

Use of the Internet also changed the configuration of the connections between companies from the old one-to-one type based on VANs, dedicated lines, and public lines to the N-to-N type. Whereas in the old

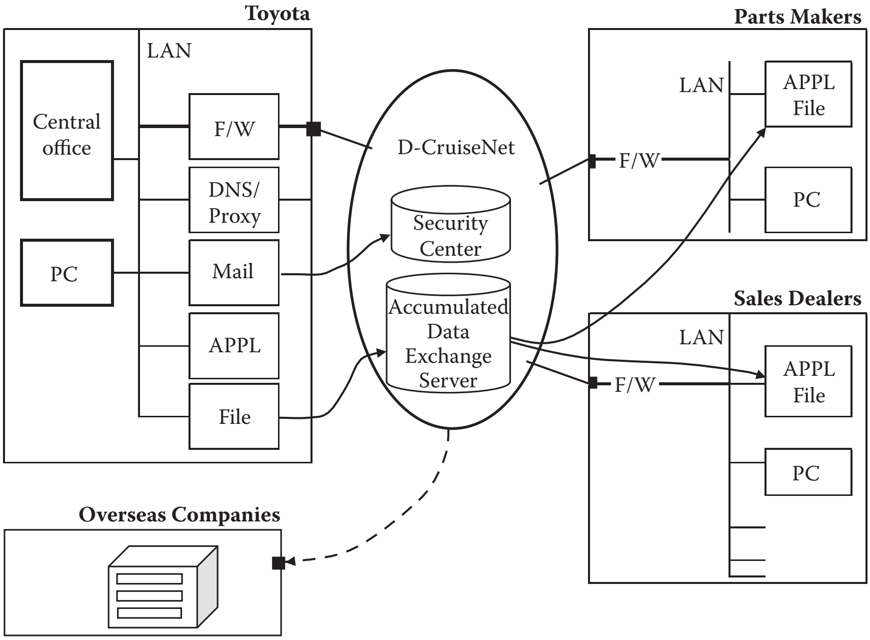


FIGURE 6.7
New TNS (Toyota Network System) (Adapted from Toda, M. 2006. *Toyota Information Systems Supporting the Toyota Way,* Nikkankogyou-Sinbun, p. 113.)

single-company EDI era most of the order-taking and issuing work was between specific partners, now it became possible for any company to access the network via its Web browser using the Internet. It was also far cheaper.

Parts Procurement Networks: JNX and WARP

In October 1998, the American automobile industry standardized its electronic commercial transactions at the same time as standardizing its network infrastructure, creating the system known as ANX (Automotive Network Exchange), in order to make it easy for parts manufacturers to deal with multiple carmakers. Before, a separate network was required for each carmaker, but joining ANX meant that parts manufacturers could now deal with many carmakers through a single network.

Since Japanese parts manufacturers also dealt with multiple carmakers, it was decided to construct a Japanese version of ANX called JNX (Japan Automotive Network Exchange). JAMA and JAPIA spearheaded this development, and the system started operating in October 1998. A number of providers were sought to manage and operate the shared networks, and Toyota's TDC took on one of them, which later became incorporated into the D-Cruise Net.

ANX and JNX were convenient for parts manufacturers, while the converse of these systems, an electronic commercial market connecting carmakers with large numbers of unspecified parts manufacturers, was also developed. The "Big Three" carmakers in the United States established an operating company for a global parts procurement market (the "e-marketplace") on the Internet, separate from ANX. The parts procurement Internet site for this was called "Covisint," and carmakers could access this site to publish the specifications, quantities, delivery lead times, and other information about the parts they needed and invite tenders from parts manufacturers around the globe. The aim was to cut costs by optimizing procurement globally, as well as to speed up transactions and reduce lead times. The Big Three also called on Japanese carmakers including Toyota to join Covisint.

However, procuring parts on the Internet required carmakers to disclose at least some of the specifications for these parts, which they were reluctant to do for the more important automobile components. Use of the system was therefore confined to general-purpose or standard parts, and Toyota did not contribute any capital to this operating company, but only joined in the parts procurement activity.

Meanwhile, Toyota itself also developed a new global parts procurement system, called WARP (Worldwide Automotive Real-Time Purchasing System), separate from JNX, introducing it first in its U.S. manufacturing subsidiary TMMNA and then into Japan. For further information, see Toda, 2006.

§ 4 PRODUCTION PLANNING SYSTEM AT NISSAN

Nissan has a production planning system which is very similar to Toyota's (see Figure 6.8). The system consists of production planning for domestic and export sales. Production planning for domestic sales will be the focus here.

First, Nissan develops annual and semi-annual production plans. For example, total production volume for its Blue Bird model is determined based on the company's profit plan or sales plan, which is based on manager's sales forecasts.

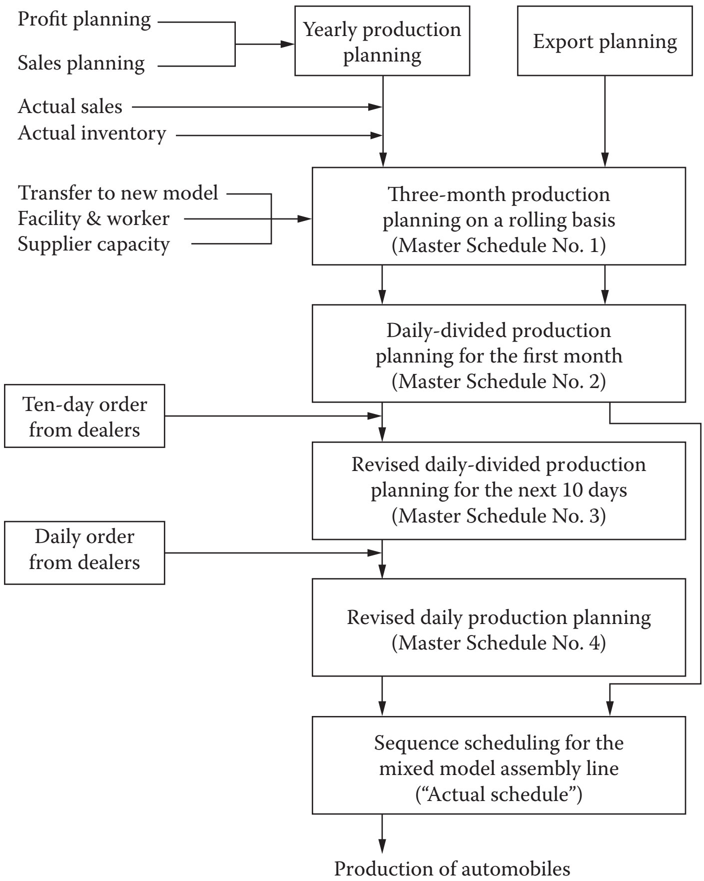


FIGURE 6.8
Nissan's production planning system.

Next, a three-month production plan, called a *Master Schedule No. 1*, is developed. Production plan information on Master Schedule No. 1 is estimated based on the actual sales volume and the inventory levels of the prior period, and considers the feasibility of using new technologies, facilities, workforces, and parts suppliers. This schedule also takes into consideration the monthly demand forecast data from dealerships.

One month before a big seasonal demand, such as March (the season of personnel transfers) or July (the month of bonus payments), the plants have to produce additional automobiles for the following month's increased sales, in addition to the demand for the current month. This type of planned inventory is also included in Master Schedule No. 1.

Master Schedule No. 2 contains the daily production volume of the most recent month of the three-month production schedule. (Total production volume of the most recent month divided by the total working days in the month.)

Based on this plan, the required workforce for production is allocated to each production process. The total necessary workforce is calculated, and an overtime work schedule (if needed) is determined. Then, an allocation of the available workforce for each operating day is performed. Once this work schedule is determined, it cannot be changed during the month since the total production volume is fixed by Master Schedule No. 1. The above production plans are based on sales forecast studied by Nissan.

After these steps, dealers contribute important data for production planning. Dealers send the 10-day orders outlining demand for color options, etc. This 10-day order includes sales forecasts and final demand by customers. Combining the 10-day order and the Master Schedule No. 2, Nissan makes *Master Schedule No. 3*. Since the 10-day order in essence acts as an adjustment function to the three-month sales forecast, Master Schedule No. 3 cannot differ much from Master Schedule No. 2.

Next, each dealer sends a daily order alteration which adjusts the 10-day order previously sent to Nissan from the dealers. For most models, the range of the adjustment should be maintained at about 20 to 50 percent. However, there are some models which dealers can change without limitation. In this regard, Nissan seems to have a superior system to Toyota because by their flexibility in accepting order changes, Nissan's production can be closer to their customers' needs. Nissan receives the daily order alteration four days before the end of the assembly period.

Information included in the daily order alterations is used to develop *Master Schedule No. 4*, the daily production schedule. Based on this daily production schedule, Nissan estimates necessary parts using MRP, and submits orders to their parts suppliers. This is the most different aspect of Nissan's system when compared to Toyota's system because Toyota estimates parts based on a kanban system.

Finally, the actual schedule is provided daily to the assembly line to determine the sequence of the models to be produced. Figure 6.8 illustrates how the four master schedules are related. Also as Figure 6.8 shows, the production schedule for exported cars does not require steps 3 and 4. The different geographic locations of export destinations and the associated lead time for delivery preclude exact adjustments to the production schedule.

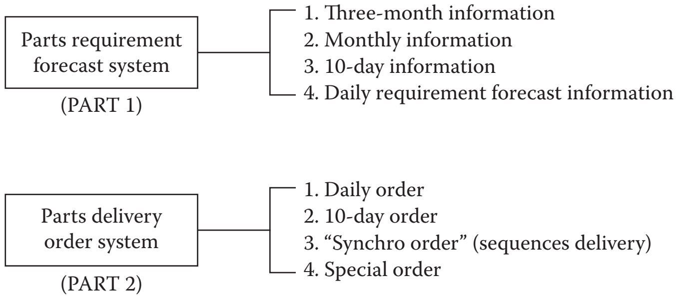


FIGURE 6.9
Nissan's parts procurement system.

Nissan's Ordering Systems from Parts Suppliers

Nissan sends four different types of information to its suppliers. This information is an *estimate* calculated in accordance with the four master schedules mentioned before (see Figure 6.9, part 1). The *actual* delivery order follows using four forms of production orders (see Figure 6.9, part 2).

Daily Order

At Nissan, daily delivery is adopted for 80 percent of the parts supply items. The daily parts order is made one day after dealers send daily order alterations (four days before the final roll-off). With this system, all necessary parts are delivered to the plants four days before the beginning of trim-in.

After receiving daily order alterations, Nissan determines its final daily production schedule. Then, using the daily production schedule and MRP, each necessary part is ordered. Toyota has implemented its decentralized production system with a pull-through system using the kanban. Since each part's production is controlled by kanban, centralized production control is unnecessary during the month. On the other hand, at Nissan, all delivery order planning is made in the central office. The central office calculates the necessary parts to order using MRP and sends this information to its parts suppliers. Usually, daily orders are delivered eight separate times each day.

10-Day Order

Followed by the 10-day production schedule (Master Schedule No. 3), the 10-day parts supply order is used to order small parts, in particular, standardized common parts necessary for North American transplants. Also, for some very small suppliers, who may not have computer terminals, the 10-day order is used instead of the daily delivery order because frequent communication through the computer system is required.

Synchronized Order

The synchronized supply order has the same function as the sequenced production schedule used by Toyota. It determines the sequence of various parts to the assembly line. Information about the type of parts necessary for a specific car is provided on the label (*broadcast*) of the car in the trimming line. The same information is sent simultaneously to the parts suppliers.

It is ideal for the parts suppliers to deliver required parts to Nissan plants just before Nissan's workers use the last part in the storage. Because each parts supplier delivers its product every hour (16 times a day), the average inventory level in the Nissan plant is about the volume of 30 minutes consumption. Also, the parts delivered by synchronized order are delivered directly to the assembly lines instead of being delivered to the parts warehouse or to parts inspectors. The total throughput time is about four to six hours after each car is conveyed to the trimming line. However, because the synchronized order is placed at the time of the trim-in, this system is not available for parts, which are distributed from suppliers who are located a considerable distance from Nissan's plant. For the synchronized order system to be effective, each parts supplier has to be located relatively close to Nissan's plants.

Special Order

The special order is a system that places orders on a monthly basis. This system is used primarily for models that are not in high demand. For instance, only 80 President model cars (Nissan's luxury model) are produced each month, which is an average of four per day. Because of the limited number of vehicles produced, Nissan does not allow daily dealer alterations for this model. Consequently, parts orders are placed monthly and are not updated on a daily basis as with other models.

7

How Toyota Shortened Production Lead Time

§ 1 FOUR ADVANTAGES OF SHORTENING LEAD TIME

Promptly adapting to meet the actual daily demand for various kinds of automobiles is the purpose of just-in-time (JIT) production. Production of various products and parts must also be scheduled in a constant quantity every day to stabilize the daily work at Toyota's plants and their parts suppliers. Having the flexibility to respond to market demand and the stability of smoothed production requires shortening the production lead time (the time interval from production dispatching to delivery of completed products).

Furthermore, a 10 percent discrepancy exists between production quantities ordered by the predetermined monthly plan and the quantities dispatched daily by kanban and the sequence schedule. This discrepancy may cause problems such as excessive inventory or workforce. To prevent the occurrence of such problems, Toyota must start production immediately when a dealer's order is received. Suppliers especially must command rapid means of production, once the order arrives. If they try to anticipate demand by producing parts in advance of receiving an order, they stand to suffer from having a surplus of inventory at month's end. Of course, production on such short notice requires a remarkable shortening of lead time so that an engine cast at 8 a.m., for example, will be ready for installation in a finished car rolling off the assembly line at 5 p.m.

The following advantages can be attributed to this shortening of production lead time:

- Toyota can achieve job-order oriented production that requires only a short period to deliver a particular car to the customer.
- The company can adapt very quickly to changes in demand in the middle of the month, so the inventory of finished products maintained by Toyota's sales division can be minimized.
- Work-in-process inventory can be significantly decreased by minimizing unbalanced production timing among the various processes and also by reducing the lot size.
- When a model change is introduced, the amount of "dead" stock on hand is minimal.

The production lead time of any product, assuming production takes place in a multi-process factory, consists of three components: processing time for supply lots, waiting time between processes, and conveyance time between processes. How Toyota minimizes the time required for each of these components is the main topic of this chapter, but before discussing this problem let us first examine these components.

§ 2 COMPONENTS OF PRODUCTION LEAD TIME IN A NARROW SENSE

In a narrow sense, lead time consists of queue time before processing, setup time, run time, wait time after processing, and move time. The components of production lead time are shown in Figure 7.1.

Figure 7.2 illustrates the relationship between these components in a multi-process production. Using process 2 in Figure 7.2 as an example, queue time before processing (B_2) is the time span that workers or materials have to wait before processing. Wait time after processing (I_2) is the time that inventory must wait before being conveyed to the next process. Although there are two types of wait times, let's regard both of them as the same for the time being. Also, let's regard the setup time plus the run time (P_2) as processing time in a general sense. As such, the components of production lead time could be narrowed down further into three categories: processing time of products, wait time, and move time.

To achieve ideal JIT production, each of these components should be shortened. Figure 7.3 shows how the respective components of production lead time can be shortened.

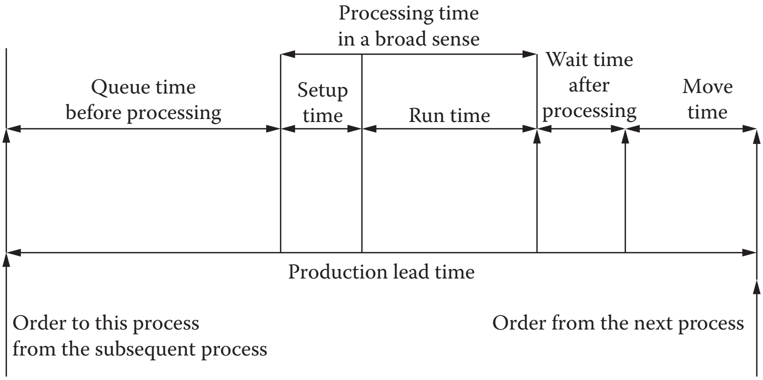
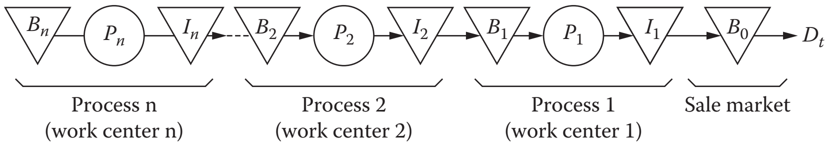


FIGURE 7.1
Components of production lead time.



where
P_i = Process i (or work-center i), which performs the production activity itself (i = 1, ...,n).
I_i = Inventory i, which was produced through the production activity of process i (i = 1, ...,n).
B_i = Line-side inventory i of parts to be processed in the Process i.
Consequently, all of B_i, P_i and l_i exist in the process i. Also, units are conveyed from I_{i+1} to B_i

D_t = Quantity of demand during the period t in the market.
B_o = Dealers' inventory in the market.

FIGURE 7.2
A chain of multi-process production.

§ 3 SHORTENING PROCESSING TIME THROUGH SINGLE-UNIT PRODUCTION AND CONVEYANCE

As a first step in reducing lead time, Toyota has refined the moving assembly concept of the conveyor system that characterizes the Ford System. This conveyor system, in its standard form, operates in accordance with a certain time interval in which one unit of a finished automobile will roll off the terminal point of the final assembly line. The operation time and conveyance time of every process in this line must be equalized. To do so,

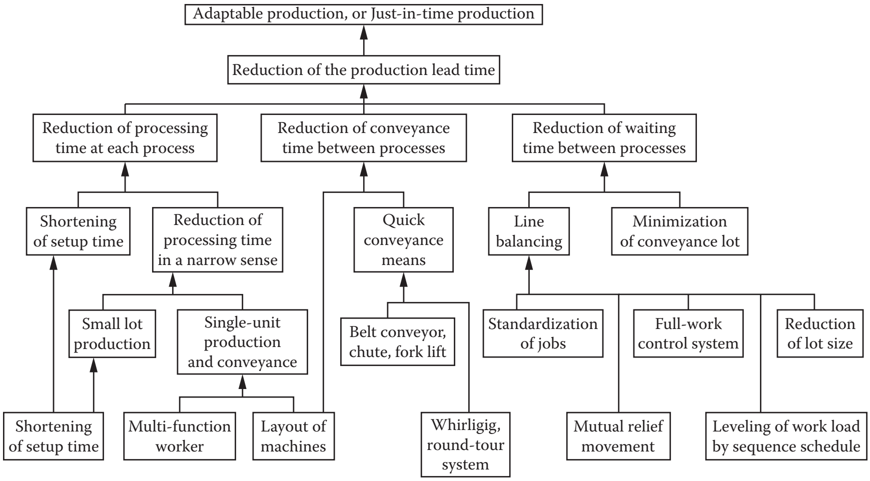


FIGURE 7.3
Framework for reducing lead time.

the assembly line must be divided to make the operation times of each workplace the same and have them start and end at precisely the same time. Also, the conveyance times between workplaces on the line must be equalized so that they too start and end at the same time. In the Ford System, the belt conveyor is used to make this equalization.

The basic idea of the Toyota Production System is based on a similar conveyor concept. According to the conveyor system, a unit of finished automobile can be produced in every cycle time, and simultaneously each unit of the output of any process in this line will be sent on to the next process. The cycle time consists of the equalized operation time and conveyance time. In Toyota, such a production flow is called *single-unit production and conveyance* ("Ikko-Nagashi" in Japanese), or *one-piece production*.

Although this concept of single-unit flow of production is now quite prevalent in most companies' assembly line systems, the processes for making parts to be supplied to the assembly line are usually based on lot production. Moreover, their lot size is still fairly large. Toyota, however, has extended the idea of single-unit flow to processes such as machining, welding, pressing, etc. Even if a process does not involve single-unit production, the operation is still limited to small lot production. In this manner, all Toyota plants use an integrated single-unit flow of production, which is all connected to the assembly line. In this sense the Toyota Production System is an extension of the idea behind the Ford System.

Functional Division of Labor Using Specialized Workers with "Lot" Production and Conveyance

Now let us imagine a plant that resembles Adam Smith's pin manufacturing (Smith, 1789, in Skinner's *Wealth of Nations,* 1970, p. 110), which has various machines for various machining operations. As shown in Figure 7.4 multiple machines are required for each type of operation, including lathing, milling, boring, welding, and polishing. The machines are grouped by type, and specialized workers are assigned to each machine. This way of laying out machines, called a *job-shop layout*, is depicted in the horizontal direction in Figure 7.4. This is called *multi-unit machine handling* in Japan.

A worker that handles only one machine (e.g., a lathe) sets a piece of work (material) on the machine, pushes the "start" button, then merely watches until the machine's automatic operation is finished. Thus the worker has the waste of "waiting time" in each cycle. However, if the worker handles six lathes, as depicted horizontally in Figure 7.4, then he will move to the second lathe while lathe #1 is cutting. In this way he can increase his productivity.

Machining operations set up in this manner are usually inclined to produce as many units as possible per lot or batch, and thus rely on production based on large lot sizes (i.e., both the amount of material to be input and the amount of output to be produced are large). As a result, the stock of products or work-in-process will be large, and the total production lead time will be as much longer as the longer carrying time of wasteful inventory.

Product-Flow Layout with Multi-Skilled Workers for One-Piece Production

To overcome the drawback of longer production lead time that accompanies job-shop layout of machines, Toyota introduced a multi-skilled worker who could handle a variety of machines, one by one, according to the timing of when a product will flow through the different machining operations. A machine layout that accommodates one-piece production in this manner is called *product-flow layout* or *flow-shop layout* in modern production management textbooks. This layout is also called *multi-process handling* in Japan.

This type of layout is depicted in the vertical direction in Figure 7.4. Lathing, milling, boring, cutting, welding, and polishing machines are laid out in order, and a single worker handles all these machines.

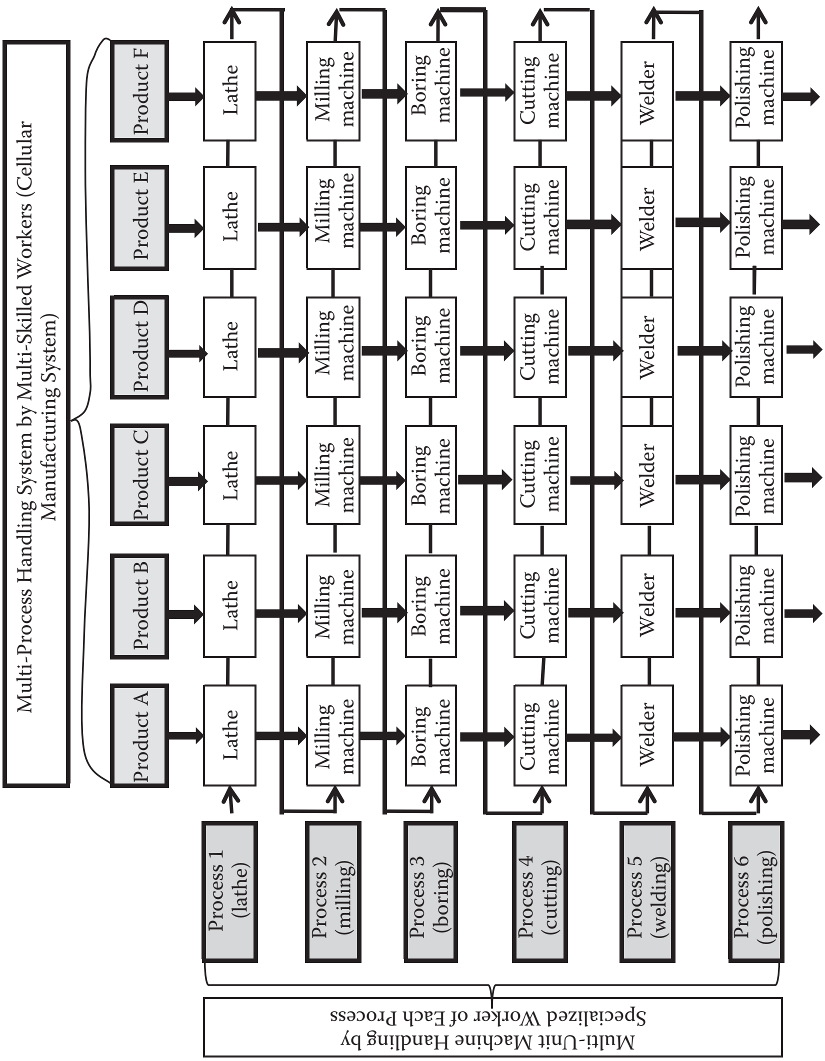


FIGURE 7.4
“Job-shop” manufacturing and “product-flow” manufacturing.

	Product Flow Layout	Job Shop Layout
Lot size	Small (usually one-piece)	Large
Lead time	Short	Long
Adaptability to demand changes	Speedy	Not speedy
Work-in-process inventory	Few	Many
Detectability of defects	Easy to find	Not easy to find
Skill of worker	Multi-skilled	Single-skilled
Machine	Small and less expensive	Big and expensive
Conveyance	Almost none	Much
Detectability of wastes	Easy to find wastes of conveyance, waiting, etc.	Hard to find wastes of conveyance, waiting, etc.
Productivity	Total optimization (productivity increase of the whole plant)	Sub-optimization (productivity increase of each machine)

FIGURE 7.5
Merits of product-flow layout compared to job-shop layout.

Comparison between Functional Division of Processes and Multi-Process Handling: A Summary

The merits of product-flow layout compared to job-shop layout are listed in Figure 7.5. Readers can easily see the disadvantages of Adam Smith's functional division of labor when seen from the viewpoint of modern production management.

Among all the merits listed for product-flow layout, the most important is that it can adapt to demand changes very quickly since production lead time can be drastically shortened.

Concretely speaking, when a variety of products must be manufactured, Smith's job-shop layout can hardly adapt to demand changes, since large lot sizes are produced, while product-flow layout can easily accommodate changes in sales mix. For example, suppose in the middle of a month the sales of product A unexpectedly declined, but the sales of product B increased. If *multi-skilled workers* are conducting *one-piece production* with a *multi-process handling system*, they can easily increase production of product B while decreasing production of product A in the middle of the month. The detailed reasoning behind this mechanism is covered in the following sections.

Adam Smith claimed that a production system based on functional division of labor using specialized workers could improve productivity. However, as mentioned previously, such a statement is not necessarily correct from the viewpoint of modern advanced theories of production management, or the *cellular manufacturing system using multi-skilled workers*. Smith criticized this system as production with very low productivity (Smith, 1789, in Skinner, 1970, p. 110).

For the purpose of this book, which tries to show the effect of the synergy created through inter-firm cooperation, the most important point is to be able to adapt to demand changes in the market and thereby minimize the risk of over-production. This can be attained by shortening production lead time. The production system of *multi-process handling by multi-skilled workers* explained below enables this key goal.

Under the requirements of smoothed production, all processes in Toyota must ideally produce and convey only one piece corresponding to each single unit coming off the final assembly line. In addition, each process must ideally have one piece in stock, both between machines and between processes. In short, all workshops must ideally avoid lot production and lot conveyance. Although Toyota has succeeded in reducing lot size, some processes operated with lot production and lot conveyance still remain. Figure 7.6 shows an overall outline of Toyota's production processes.

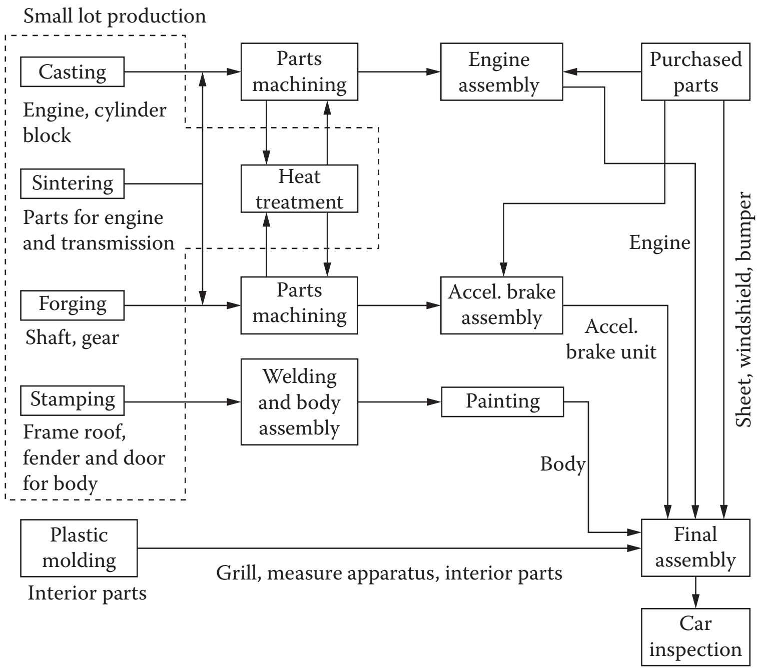


FIGURE 7.6
Toyota's production process.

Outline of Toyota's Plants

The processes can be roughly classified into five categories:

- ***Casting and pressing***. Includes the casting process, which is mainly the foundry of engines, the sintering process for parts, the forging process for shafts and gears, and the pressing process for bodies. These processes involve lot production because they have large-scale automated plants. Some of them, however, have fairly small lot sizes (mostly for two shifts' use) because of speedy setup actions.
- ***Parts machining***. Engaged mainly in small lot production or single-unit production and conveyance.
- ***Parts assembling***. Workshops to assemble engines or accelerator and brake units. These processes are engaged in single-unit production and conveyance.
- ***Body welding***. Workshops that weld pressed parts, assemble them for a car body, brass, sand, and finally paint these parts. One-piece production and conveyance is the method used in these processes.
- ***Final assembly line***. Operated by one-piece production and conveyance directed by the sequence schedule. Withdrawal kanban are attached to parts in racks beside the final assembly line so that the workers can easily pick them up. Parts such as engines, accelerator units, and brake units are attached to the auto body here, and various measurement apparatuses, sheets, windshields and bumpers, and so on, are also attached here. After inspection, the automobile will be conveyed to the holding yard of Toyota's sales division.

Shortening Processing Time through Small-Sized Lot Production

In processes such as casting, forging, and stamping that use lot production (also called batch production), lot size must be reduced to shorten processing time. It is very simple logic that reduction of the lot size leads to shortening of production hours. Suppose processing time per unit of part A is one minute and the lot size is 3,000, then the total processing time amounts to 50 hours. However, by reducing the lot size to 300, that is one-tenth of the initial lot size, its processing time can be only five hours. In this example, the processing time of part A has decreased to five hours from 50 hours just by reducing the lot size. This simple logic is basic to shortening the lead time by reducing the lot size.

In the previous example, however, since 3,000 units of part *A* are needed, production of the small lot size (300) must be repeated 10 times. Additionally, parts *B* and *C*, needed at the same time, are also produced in small lot sizes. Therefore, during the 10 production runs for part *A*, the production of parts *B* and *C* must be inserted.

Also, if the setup time in changeover of the lots is kept constant, the total setup time will increase in proportion to the increased number of changes of the lots. Therefore, the setup time must also be shortened when lot sizes are reduced.

In the previous example, suppose the setup time is one hour and processing time per unit is one minute. In this case, if the production lot is 3,000 units, the total production time (setup time + total processing time = one hour + [one minute × 3,000]) required is 51 hours. However, by shortening the setup time to six minutes, or one-tenth of the initial setup time, the production lot size can be reduced to 300, or one-tenth of the initial lot size. The reason is that even if the production is repeated 10 times with lot sizes of 300, the total production time and output will be the same as before. In short, the total production time is still 51 hours (6 minutes + [one minute × 300] × 10).

In general, if the setup time was reduced to $1/N$ of the initial time, the lot size could be reduced to $1/N$ of its initial size without changing the loading rate of the process in question.

Advantages of Small Lots in the Production of Different Products

Again, assume there are three kinds of parts: A, B, and C. The processing time of any part, per unit, is one minute and the setup time of alternating the lots is one hour. Further, the lot size of any part is 3,000. Then, to get these three kinds of parts requires a total production time of 153 hours (51 hours × 3).

Here, if the lot sizes of parts A, B, and C were reduced to one-tenth of their initial size and the setup time is reduced to one-tenth of its initial time, the necessary time to produce these three kinds of parts would be only 15 hours and 18 minutes, when it had taken 153 hours before. Figure 7.7 illustrates this example.

In this manner, shortening the processing time without decreasing productivity will be accomplished by reducing setup time and lot size. This is especially effective when many varieties of products are produced.

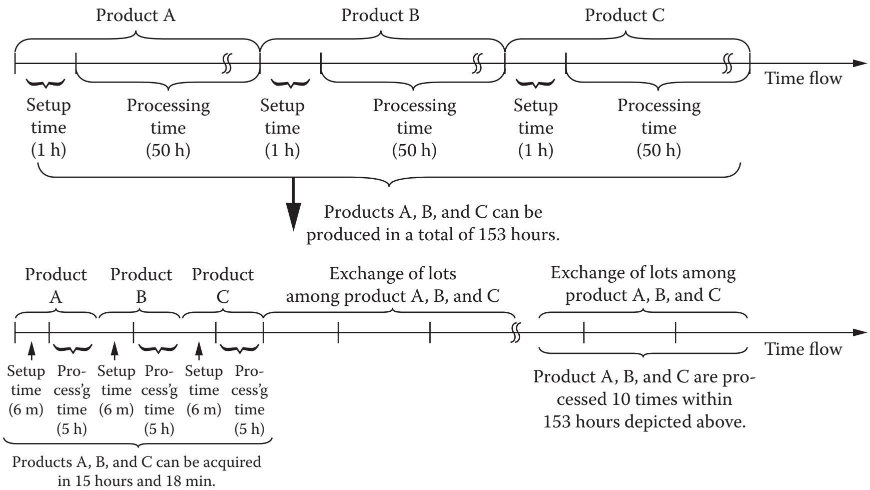


FIGURE 7.7
Shortening processing time for a variety of products through small-lot production.

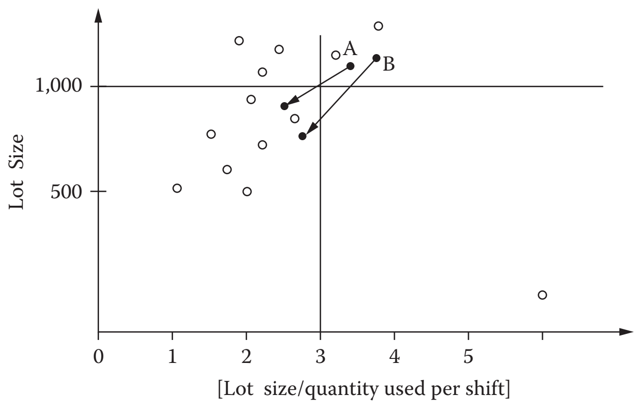


FIGURE 7.8
Lot size reduction control chart.

Control Chart of Lot Size Reduction

As has always been the case in automobile manufacturing, the lot size of stamped parts of an automobile is fairly big. Therefore, a lot size reduction control chart, as seen in Figure 7.8, is recommended.

In this figure, the lot size quantity is plotted on the vertical axis (ordinate) and the lot size quantity divided by the quantity used per shift is plotted on the horizontal axis (abscissa). The abscissa shows how many shifts can use the quantity of parts provided by one lot. Since a lot size covering more than three shifts is too big, the vertical line at the abscissa value 3 has been drawn. A horizontal line crossing the ordinate value 1,000 is drawn as a standard. Then various stamping parts are plotted in the figure. At first, most of them appeared in the right upper part, but a control target is set so as to bring them one by one to the left lower part. An example target, as seen in Figure 7.8, is to bring the marks for parts A and B to the spot the two arrows are pointing to.

§ 4 SHORTENING WAITING TIME AND CONVEYANCE TIME

How to Balance Each Process

Waiting time is defined as the time spent by parts-in-process waiting to be processed and assembled, or by completed products waiting to be withdrawn by a subsequent process; it excludes the conveyance time. The first type of waiting times is often caused by a delay in a preceding process making the subsequent process wait. The second is often caused by a delay in a subsequent process making the preceding process wait. The latter arises in many cases under a pull system like kanban. Both causes are the results of unbalanced production time between processes.

Under the push system, a large-sized lot in the preceding process may force the subsequent process to wait. In such a case under the pull system, the preceding process is contrarily apt to produce intermittently, repeatedly stopping and starting its production without smoothing. To shorten the wait time in this process, line balancing must be achieved. The first priority is to achieve production of the same quantity in the same amount of time in each process. Although the cycle time must be the same in all processes on the assembly line, there will be some variance in the actual operation time among processes depending on minor differences in workers' skills and capabilities. To minimize these differences, standardization of actions or operating routines is very important, and the supervisor or foreman must train workers to master the standard routines (see Chapter 10).

At the same time, what Toyota calls *mutual relief movement* should be applied to make up for delays in some processes. At Toyota, the point connecting two workers or two processes is designed so that the workers will be able to help each other. This point is similar to the baton touch zone in relay races of track and field events. For example, when one part is completed by a team of workers in a certain line, the part must be handed on like a baton to the next worker. If the person in the subsequent process is delayed, the preceding worker should set up and take off the work on the subsequent machine. When the subsequent worker returns to his initial position, the preceding worker should hand the work to him immediately and go back to the preceding process. This same system would apply in reverse if the preceding worker was delayed. Friendships may be cultivated through such teamwork under the mutual relief system.

The most serious problem with regard to line balancing is the existence of capacity differences among the machines used in each process. The *full-work control system* described in Chapter 3 is used to cope with such capacity differences.

Shortening Waiting Time Caused by Pre-Process Lot Size

To shorten the waiting time caused by a big lot size in the preceding process, the conveyance lot size need only be minimized (unless there are many varieties of parts). This approach allows production with a large lot size for certain kinds of products, but it also requires that the product be conveyed to the subsequent process in minimal units. In other words, even if the product lot is made up of six hundred units, when one unit is completed, it should be conveyed immediately to the next process.

The effect of this approach is illustrated by the following example. Suppose there are three processes and each takes one minute to produce one unit. One unit of a product will require three minutes to go through the three processes. If six hundred units must be produced, one process requires six hundred minutes, or ten hours, and all three processes will take 30 hours. However, if each single unit is conveyed to the subsequent process as soon as it has been processed by the preceding process, then processes 2 and 3 can operate at the same time as process 1. Process 2 will have to wait while process 1 is finishing the first unit, but only for one minute. Process 3 will also have to wait while process 2 is finishing its first unit, but again only for one minute. To produce six hundred units through these three processes, the total time required is:

600 minutes + 1 minute + 1 minute = 602 minutes.

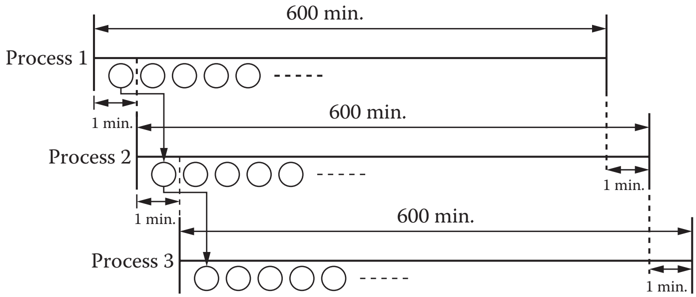


FIGURE 7.9
Relationship between processes and processing times.

This relationship is depicted in Figure 7.9. However, if process 1 and 2 each had one unit of inventory of finished output of its process on hand at the beginning of each month, the above waiting time of one minute each would disappear. Then it would be necessary to spend only six hundred minutes to produce six hundred units in the three processes.

In a case in which lot production and lot conveyance are applied to n processes, the total processing time = $n\ T$, where T = processing time in each process. But if single-unit conveyance is applied to n processes with each preceding process having output a single unit of finished inventory, the total processing time will be only T; that is, it will be shortened by $1/n$.

If the conveyance lot is only a single unit, however, the frequency of delivery must be increased, and the problem of minimizing conveyance time arises.

Two Steps for Conveyance Improvement

Improvement of the conveyance operation can be achieved in two steps: layout of machines and adoption of quick conveyance means. The layout of different kinds of machines should be in accordance with the flow of processes instead of by machine type. If there are many kinds of products, common or similar processes for these various products should be grouped together. Next, quick means of conveyance such as the belt conveyor, chute, or forklift should be used to connect the processes. The use of the whirligig beetle system and round-tour mixed-loading system by the subcontractor will help promote the continuous flow of products among processes.

§ 5 A BROAD APPROACH TO REDUCING PRODUCTION LEAD TIME

The Japanese JIT production system is aimed at flexible adaptation to fluctuations in demand quantity and variety in the market. Here the term *flexible* means "with short production lead time." The production lead time is the total completion time of every operation necessary for producing the merchandise. The necessary operations to produce products are: demand analysis, planning and designing of products, preparations of facilities (production engineering), manufacturing, and distribution of products to customers.

The JIT goal can be achieved by considering all necessary lead time required for each of the operations. Figure 7.10 shows the system of operations directly related to production.

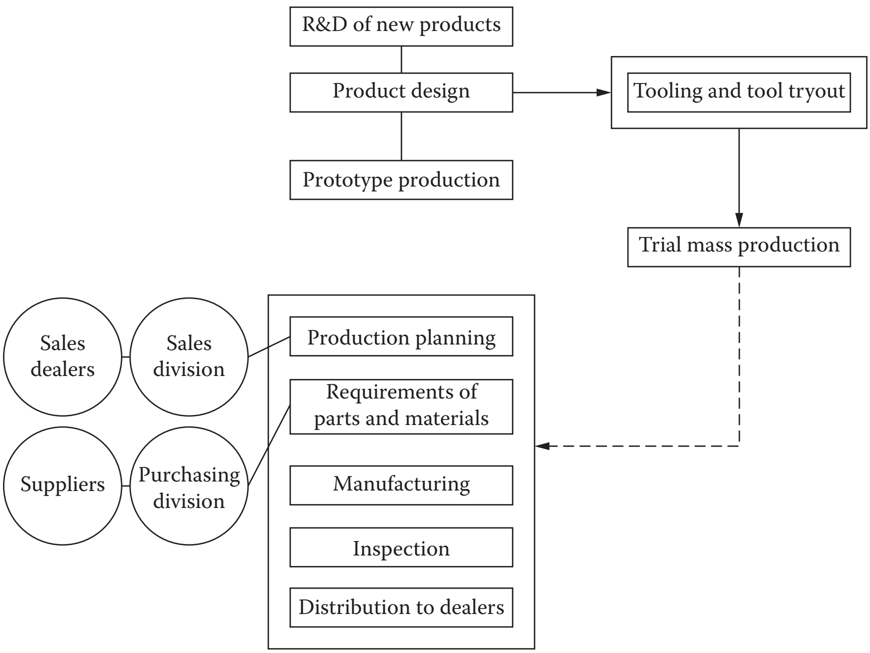


FIGURE 7.10
System of operations surrounding production.

Five Principles for the Ideal Factory Automation

By looking at the entire production system operation, it is possible to supply timely, well-made products demanded by customers. The products will be the best in terms of quality, function, and price.

For example, in the development of a new product, it is necessary to promptly grasp the market need and quickly connect it to development of the product. For this purpose, establishing new organization structures is required. Changing organizational structure to a flatter type of hierarchy and simplifying the decision-making steps allows for quick adaptation and enables prompt decision making on both clerical and management levels. An information network between departments and using computer-aided design (CAD) and computer-aided manufacturing (CAM) to aid in shortening design lead time would also be beneficial.

Here let us consider in detail production preparation and manufacturing systems. Production preparation involves preparing production facilities, conveyance machinery, and storage equipment (automatic warehouses), and so on, and is usually assigned to the Production Engineering Department. On the other hand, the manufacturing system is a production control system mainly aimed at creating a smooth flow of products throughout the plant. The Production Management Department is usually responsible for the components within the manufacturing system.

Within the production preparation system, tooling and tooling tryout are obvious candidates for reducing lead time. If the problem is approached from the perspective of JIT production control, it is possible to reduce manufacturing lead time as well.

From the JIT point of view, the following facility preparations would be required:

- *Install multiple compact facilities to enable small lot size production*. Production via large lot sizes is apt to create huge inventories between processes because the parts will have to sit and wait before being processed by the next process. A longer run time is also required to finish processing the large lot. As a result, the inventory of completed products becomes a large lot as well. For example, in an aluminum foil factory, an annealing furnace softens coils of pressed aluminum foil and then removes the residual oil which collects on the aluminum foil. A small coil of aluminum foil can be heated in a day, but a wide coil requires several days of heating. The furnace was installed in the age of small varieties and large runs. It was expected to heat large lot sizes on a wide aluminum coil, but as already mentioned, this process requires a long time. Under such a condition, the process becomes a bottleneck and a detriment to the shortening of the whole production lead time.

- *Develop a technology for shortening chemical reaction time*. The delay of a process operation is often caused by slow chemical reactions. The reaction in eliminating oil from the aluminum foil in the annealing furnace is one such example. Another example can be found in pharmaceutical or cosmetic plants. If a chemical reaction time for inspecting finished products takes too long to complete, then a bottleneck will occur at the end of the process and create delays for all preceding processes within the plant.
- *Eliminate excessively speedy facilities*. Raising the processing speed at each process is important for reducing the run time. However, the process speed is sufficient if it is within the cycle time determined by the demand in the market place. Therefore, facilities that can produce products piece-by-piece according to the cycle time should be installed. The product cycle time will vary depending on the type and market conditions of each industry.
- *Connect machines so products can flow rapidly*. Machines or processes should be joined in a conveyor-like system or a cellular layout, rather than in a job shop or functional layout. This is done by building up a transfer line with many machines. The transfer line should contain buffer inventories stored at several places between machines. These buffer inventories can prevent an immediate line-stop when a single machine in the line breaks down. The buffer inventories are replenished by the "pull system" (a concept of the kanban system of JIT production). *Note:* Under a large-lot production scheme, the pull system will not make any sense because it will neither shorten the production lead time nor reduce the inventory. This is why the pull system should only be adopted for small lot production.
- *Plan flexible manufacturing systems (FMS) for the future*. Consider how FMS should be in the future. Presently, there are three types of FMS. One type is a flexible machining cell (FMC), which is a cell constructed by a machining center (or turning center), a robot, and a palette pool. Another type of FMS places machining centers in a flow line, and the third FMS is of the job shop variety (also called random access FMS). In this type of FMS, various work pieces are

conveyed at random and identified at a particular machine where they are set up and processed. This FMS also facilitates automatic exchange of tools and control of work-in-process inventory.

Of these three kinds of FMS, the FMS with the flow line is the most desirable for use with the JIT production system. However, the FMS in use today do manage to perform flexible processing for a group of similar parts. If a production technology is developed that enables flexible processing even among different types of parts, the flow-line type FMS will make it possible to process various products with a short lead time. The author is expecting such an FMS will be invented.

Concerning the manufacturing system, lead times can be broken down into the following types as depicted in Figure 7.11:

L_1 = lead time of data processing
(from demand forecasting to production dispatching)

L_2 = lead time of the manufacturing activity itself

L_3 = lead time of delivering completed products to customers

Shortening each of these lead times will depend on the market movement, flexibly adapting to market fluctuations, and reducing costs as much as possible. The Toyota Production System works on shortening an L_2 type of lead time.

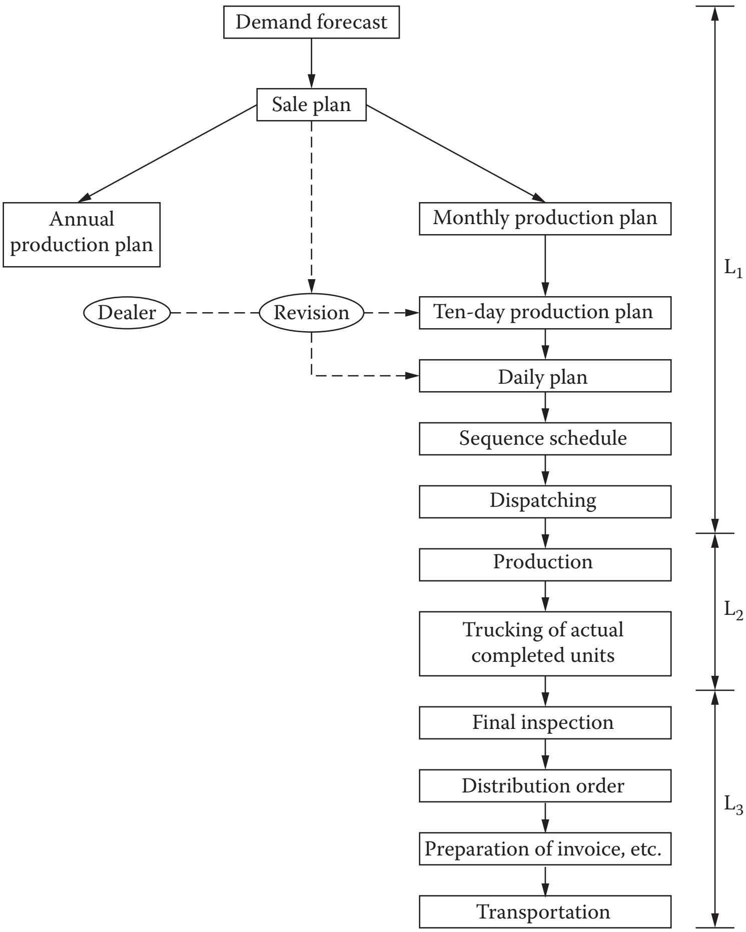


FIGURE 7.11
Three types of lead time in a manufacturing system.

8

Machine Layout, Multi-Functional Workers, and Job Rotation Help Realize Flexible Workshops

Toyota manufactures a variety of automobiles with many different specifications. Each type of car is always subject to fluctuations in demand. For example, the demand of car A might decrease, while at the same time, car B might increase in its demand. Therefore, the workload at each car line in the plant must be frequently evaluated and periodically changed. Continuing an example, a number of workers at the line for car A would have to be transferred to the line for car B so that each line can adapt to the change in demand with the minimum necessary number of workers.

Moreover, even though the demand of all types of products may be reduced simultaneously because of a general economic depression or some foreign export restriction, the company should still be able to reduce the number of workers at any line by taking out temporary workers or extra workers coming from related companies.

§ 1 SHOJINKA: MEETING DEMAND THROUGH FLEXIBILITY

Attaining flexibility in the number of workers at a workshop to adapt to demand changes is called *Shojinka*. In other words, Shojinka in the Toyota production system means to alter (decrease or increase) the number of workers at a shop when the production demand has changed (decreased or increased).

Shojinka has an especially significant meaning when the number of workers must be reduced due to a decrease in demand. For example, at a line, five workers perform jobs which produce a certain number of units. If the production quantity of this line was reduced to 80 percent, the number of workers must be reduced to four ($5 \times 0.80 = 4$); if the demand decreased to 20 percent, the number of workers would then be reduced to one.

Obviously, then, Shojinka is equivalent to increasing productivity by the adjustment and rescheduling of human resources. What was called a flexible workshop in the title of this chapter is essentially a workshop that is achieving Shojinka. To realize the Shojinka concept, three factors are prerequisite:

1. Proper design of machinery layout.
2. A versatile and well-trained worker—that is, a multi-functional worker.
3. Continuous evaluation and periodic revisions of the standard operations routine.

The machinery layout for Shojinka at Toyota is combined U-form lines. Under this layout, the range of jobs for which each worker is responsible can be widened or narrowed very easily. However, this layout assumes the existence of multi-functional workers.

Multi-functional workers at Toyota are cultivated through the unique *job rotation system*. And, finally, the revision of the standard operations routine can be made through continuous improvements in manual jobs and machineries. The purpose of such improvements is to reduce the necessary number of workers even in the period of increased demand.

The relationship among these important prerequisites is shown in Figure 8.1. This chapter is devoted to explaining the factors affecting the widening or narrowing of the range of jobs for each worker.

§ 2 LAYOUT DESIGN: THE U-TURN LAYOUT

The essence of the U-turn format is that the entrance and exit of a line are at the same position. The U-turn layout has several variations, such as the concave () and circle forms (Figure 8.2). The most remarkable and important advantage of this layout is the flexibility to increase or decrease the necessary number of workers when adapting to the changes

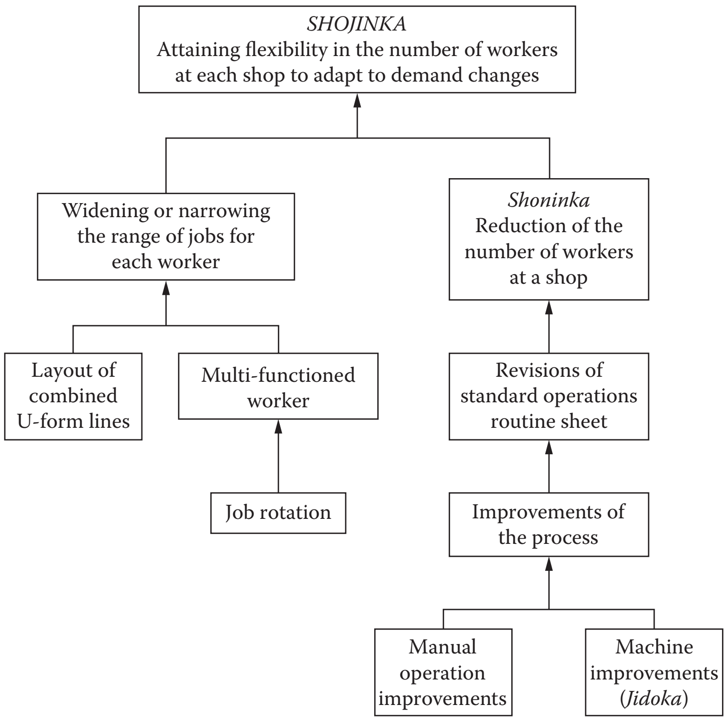


FIGURE 8.1
Causal factors to realize Shojinka.

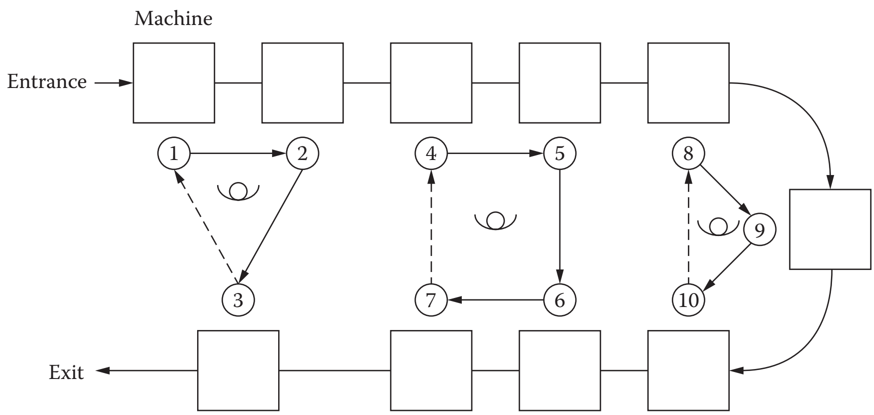


FIGURE 8.2
U-form layout.

in production quantities (changes in demand). This can be realized by adding or reducing the number of workers in the inner area of the U-shaped workplace (Figure 8.2).

Just-in-time pull production also can be achieved in each process. A unit of material can pass into the entrance of the process when one unit of output leaves through the exit. Since such operations are performed by the same worker, the quantity of work-in-process within the layout can always be constant. At the same time, by keeping a standard inventory quantity at each machine, unbalanced operations among workers will be made visual, so that improvements in the process can be evoked.

Finally, the U-turn format allows regions or areas to be developed for specific worker operations. Systems using automatic large-scale machines often have workers located only at the entrance and exit. A chain hanger is one such example. If the positions for loading and unloading the material are different, two persons will always be needed, and each worker often has idle time or waiting time. However, if the loading and unloading positions are set at the same point on the line, one worker can handle both the entrance and exit jobs.

Improper Layouts

Improper layouts that Toyota has avoided can be divided into three major categories: birdcages, isolated islands, and linear layouts.

Bird Cage Layouts

The simplest form of machine layout calls for one worker assigned to one type of machine. This type of layout has a major disadvantage: the worker has waiting time after he has loaded the work piece into the machine and the part is in process. To avoid such waiting times, two or more stands containing the same type of machine can be laid out around the worker (Figure 8.3). This type of layout is called a birdcage layout; they are usually triangular, rectangular, or rhombic in shape.

By making each worker handle multiple machines of the same type, the production quantity per worker can be increased. Although this method is much improved over the single machine layout, the production quantity per worker increases; thus, the inventory of semi-finished or intermediate inventory produced at each station also increases. As a result, production balancing between stations is difficult to achieve and these

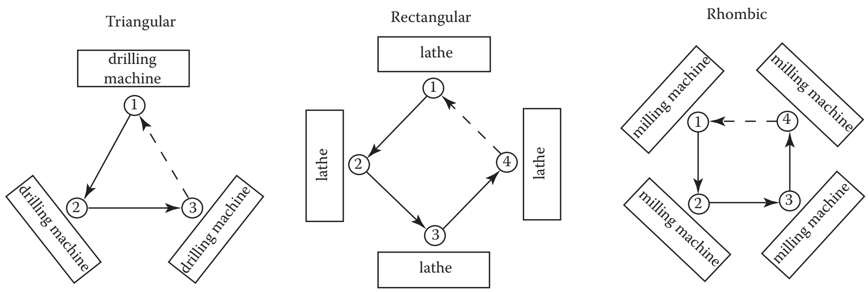


FIGURE 8.3
Types of birdcage layouts.

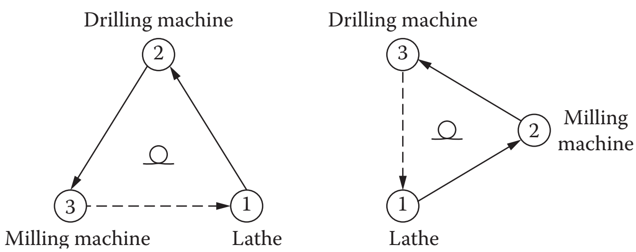


FIGURE 8.4
Isolated island layouts.

semi-finished products cannot flow smoothly and continuously through the various production processes. *Synchronization* among stations is hardly achieved. In turn, the lead time to produce finished goods rises dramatically.

Isolated Island Layouts

To avoid excessive intermediate inventories from each station and decrease the conveyance time, the layout of machines must be improved to increase the speed of producing a finished product. Therefore, the layout of machines should be in accordance with the sequential order of processing a part (see Figure 8.4). This layout assumes the existence of a multi-functional worker, and enables a continuous, smooth flow of products among different types of machines; it also ensures a continuous walking route with the least distance for each worker. This type of layout is called an *isolated island layout*.

Toyota rejects all types of the isolated island layout because of the following disadvantages:

- When the entire factory is under this layout, workers are separated from one another and, as such, cannot help each other. It is difficult to attain total balancing of production among the various processes. Unnecessary inventory still occurs among different processes. Mutual relief movement (Chapter 7) cannot be applied to isolated islands.
- Since unnecessary inventory can exist among isolated islands, worker waiting time will be absorbed in producing this inventory. Thus, the reallocation of operations among workers to respond to changes in demand is difficult in this process.

The isolated island layout is based on the methods engineering theory that a worker should never walk at all while working at a certain position. Such an idea was held even by Henry Ford. This idea is correct when productivity is viewed according to the efficiency of individual workers; however, it is incorrect when viewed according to line balancing within a whole factory and minimizing the total number of laborers.

Concerning the isolated island, the way of using a conveyor is also important. A conveyor is often used only to convey products from place A to place B. In this case, the worker at place A is separated from the worker at place B, and therefore they cannot help each other with the job. Toyota will remove the conveyor in such cases.

Linear Layouts

To overcome the demerits of an isolated island layout, different types of machines can be laid out in a linear form (Figure 8.5). Under this layout, workers must walk between machines. This is one of the typical characteristics of Toyota's layout.

Using this linear layout, one of the major disadvantages of isolated islands (unnecessary stocking of outputs among processes) can be eliminated, thereby allowing products to flow smoothly and quickly among machines. One problem that cannot be eliminated using the linear layout, however, is the inability to reallocate operations among workers to adapt to changes in demand.

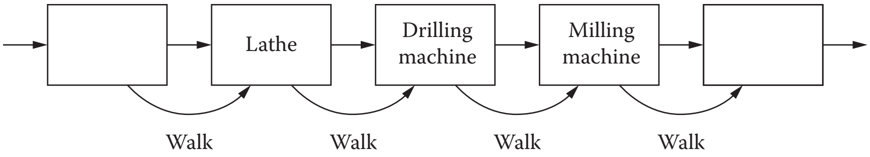


FIGURE 8.5
Linear layout.

Another problem associated with this system is that when machines are set out in a linear form, each line is independent from other lines. In this situation, the repositioning of operations among workers in accordance with the demand for products often requires a fractional number of workers, such as 8.5 persons. Since 0.5 manpower is not possible, it must be rounded up to one person. As a result, the worker will have some amount of waiting time, or excessive production will occur.

As an example, one unit has been produced in a two-minute cycle time by only one worker. Assume that the demand of cars was increased and that the cycle time was reduced to 1.5 minutes per unit. In this case, if a worker can normally finish half of the total jobs for making one unit of product within one minute, then an additional worker must be introduced to this process to complete the other half of the total jobs. As a result, each of the two workers in this process must have 0.5 minutes of waiting time in every cycle time. Or, if the first worker performed more jobs in 1.5 minutes without any idle time, the second worker must have one full minute of idle time.

Combining U-Form Lines

To overcome the problem of fractional numbers of workers, Toyota eventually decided to combine several U-form lines into one integrated line. Using this combined layout, the allocation of operations among workers in response to variations in production quantities of automobiles can be accomplished by following the procedures of setting the standard operations routine.

The following example will show how Shojinka can be attained using this concept. Suppose there is a combined process that consists of six different lines (A–F), and each line is manufacturing a different gear (Figure 8.6). According to the monthly demand of products in January, the cycle time of this combined process was one minute per unit. Under this cycle time,

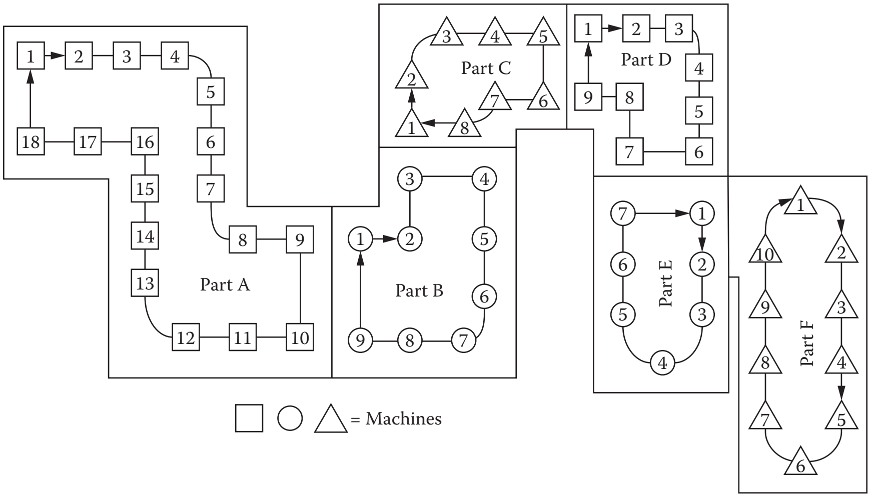


FIGURE 8.6
Combined line making six kinds of parts (A–F).

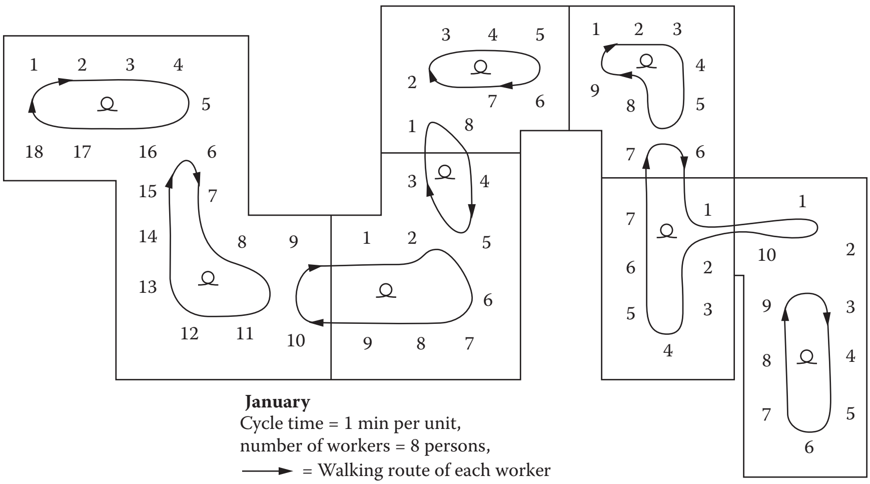


FIGURE 8.7
Allocation of operations among workers in January.

eight persons were working in this process (Figure 8.7), and the walking route of each worker is described by the arrow line.

In February, however, the monthly demand for products was decreased and the process cycle time was increased to 1.2 minutes per unit. As a result, all operations of this combined line were reallocated among the workers and each worker now had to undertake more operations than

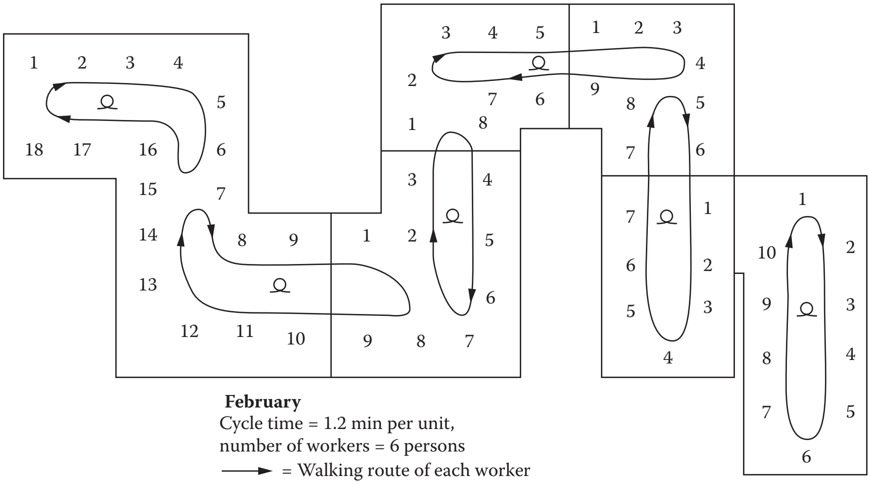


FIGURE 8.8
Allocation of operations among workers in February.

in January. Figure 8.8 shows that the walking route of each worker was expanded under the new allocation of operations. In this case, worker I will do as an additional job some of the operations worker 2 was doing in January. Worker 2 will also undertake an additional job that was previously accomplished by worker 3 in January. The result of expanding the walking route of each worker is that workers 7 and 8 can be omitted from this combined line. Thus, the fractional manpower that might have occurred in a linear form layout was absorbed in various individual lines under this combined layout.

Cellular Manufacturing

As stated, the connected U-turn layout shown in Figure 8.6 encompasses a large machining line that machines six kinds of gears. The gears flow one at a time through each process in the U-turn layout (following "one-piece production"). Each individual U-turn process is a kind of *cell*, where either one or two workers are working. However, when many small cells are connected as in Figure 8.6, it becomes easier to increase or decrease the number of workers. This phenomenon is often emphasized as a key merit of the so-called cellular manufacturing system that is popular in standard textbooks on production management.

Since the U-turn process or U-formed line of the Toyota production system is similar to the cell production system, which is very popular in

Japan, let us examine cellular manufacturing briefly. The definition of cellular manufacturing in academic terms is discussed below. (Stevenson, 1990, pp. 354–356, and Swamidass, 2000.)

Process design is based on either a job-shop type machine layout or a product-flow type machine layout, as explained previously. Both cellular manufacturing as described in textbooks and the so-called cell production system in Japan belong to the latter type. This type of process design assumes that *similar* products are flowing through the process. Consequently, even in Japanese cell systems, a specific cell deals with the same or similar products. Therefore, by applying "group technology," similar products are preselected for processing in the cell. In other words, to implement cellular manufacturing, items or parts with similar physical forms or similar engineering procedures must be grouped into *item families* or *parts families*. As a result, various machines are identified by the group of machining operations necessary to process sets of similar items (or part families).

This is a typical example of the application of group technology. Japanese practitioners at production sites are not necessarily conscious of applying group technology, but in reality, without applying this idea, the "cell production system" cannot hold.

Cellular manufacturing means a production system with a machine layout arranged so that various machines are collected in a place called a *cell*. A cell is typically a miniature version of flow-type layout. A cell sometimes consists of just one machine, but often consists of a series of machines among which parts do not move by conveyer, or multi-flow-lines connected by a conveyer.

Cellular manufacturing has various merits, such as less throughput time, less conveyance, less work- in-process stock, less setup time, and enhanced worker morale.

From these explanations, it is clear that there is no difference among cellular manufacturing, Toyota's U-form process and the "cell production system" popular in Japan.

§ 3 ATTAINING SHOJINKA THROUGH MULTI-FUNCTIONAL WORKERS

Figure 8.1 showed that the ability to widen or narrow the range of jobs performed by each worker is a key ingredient in achieving Shojinka. Carefully designed machine layouts help develop this ability, but machine layouts alone cannot achieve Shojinka.

Remember that the true meaning of Shojinka is the ability to quickly alter the number of workers at each shop to adapt to changes in demand. When viewed from the side of the individual worker, Shojinka demands that the worker be able to respond to changes in cycle time, operations routines, and in many cases, the duties of individual jobs. In order to respond quickly, the worker must be multi-functional; that is, trained to be a skilled worker for any type of job and at any process.

Cultivating Multi-Functional Workers through Job Rotation

Obviously, cultivating or training the individual worker to become multi-functional is an important part of achieving Shojinka. Toyota cultivates their workers using a system called *job rotation*, where each worker rotates through and performs every job in his workshop. After a period, the individual worker develops proficiency in each job and thereby becomes a multi-functional worker.

The job rotation system consists of three major parts. First, each manager and supervisor must rotate through every job and prove their own abilities to the general workers in the shop. Second, each worker within the shop is rotated through and trained to perform each job in the shop. The final step is scheduling the workers through job rotation at a frequency of several times each day.

Toyota first implemented a job rotation plan at their Tsutsumi Factory (Machining Plant No. 2) where rear-wheel differential carriers are processed and assembled. Mr. Yuzo Suzuki implemented this plan at Tsutsumi in 1980. The author is indebted to his report.

The organization of the plant is shown in Figure 8.9. Notice that at each works, shop, and line there are general foremen, foremen, and line chiefs, respectively. General workers are the responsibility of each line chief with a total of 220 employees working at the plant. Rotation of workers among jobs was implemented following the three steps previously discussed.

Step 1: Rotation of Supervisors

To cultivate general laborers into multi-functional workers, the managers and supervisors must first display themselves as models or examples of the multi-functional worker. As a result, all of the general foremen, foremen, and line chiefs (about 60 persons total) were rotated among each work's shop and line in this plant. The foremen were transferred among shops of

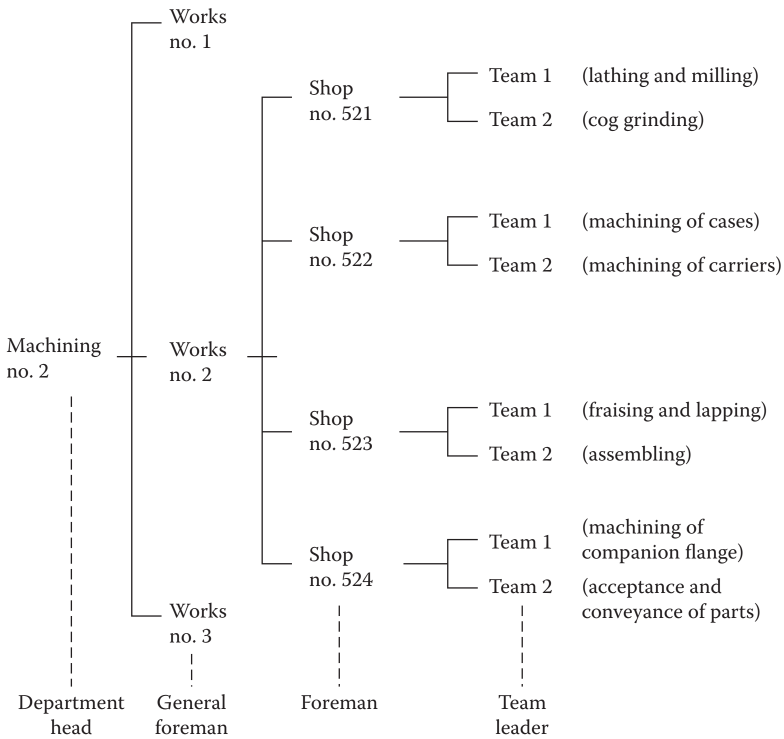


FIGURE 8.9
Organization of machining plant no. 2.

the same works. Since the rotation of all managers and supervisors took three years to accomplish, the job rotation plan was implemented as part of a long-range planning program.

Step 2: Rotation of Workers within Each Shop

To accomplish this step, a job-training plan must be scheduled for general workers as was planned for shop number 523 in Figure 8.10. This plan was set by the general foreman so that every worker in his shop could master any kind of operation at every process in the shop.

To promote the training plan, a multi-functional worker rate for each shop must be formulated using the following formula:

$$\frac{\sum_{i=l}^{n} \text{number of processes each worker } (i) \text{ has mastered}}{\text{total number of processes within the shop} \times \text{n}}$$

where n = total number of workers at the shop.

Job Training Plan Sheet (shop no. 523)

● = Planned to train this year
◑ = In training
○ ⦶ = Trained already

Line name	160 mm differential carrier assembly line							
Processes / Workers	1	2	3	4	5	6	7	8
A	○	○	○	○	○	○	○	○
B	◑	⦶	○	○	○	⦶	⦶	⦶
C		⦶	⦶	⦶	⦶			
D	○	○	○	○	○	○	○	○
E	⦶	○	○	○	○	○	⦶	⦶
F	●	●	◑	○	○	○	○	○
G	○	○	○	○	○	○	○	○
H	○	○	○	○	○	○	○	○
Foreman	⦶	○	○	○	○	○	○	○

FIGURE 8.10
Job training plan sheet.

Toyota's goal for this rate was 60 percent for the first year (1977), 80 percent for the second year (1978), and 100 percent for the third year (1979). However, the actual average rate attained in 1979 at the Tsutsumi Plant was 55 percent. This low figure was due to the physical health and strength of the typical worker, the number of extra workers from outside-related companies, and the number of temporary seasonal and newly employed laborers. The actual training time for a worker to master each job usually varies from several days through several weeks.

Step 3: Job Rotation Several Times per Day

When the aforementioned multi-functional worker rate became high, Shojinka could be realized, and job rotation could be made every week, or in many cases every day. In some advanced cases, all workers could be rotated among all processes of the line in two- or four-hour intervals.

An example of this advanced job rotation occurred in line 2 of shop number 523. In this line, the 160 mm differential carriers are assembled by eight workers (excluding the line chief as a relief man) within its cycle time of 26 seconds. The layout and standard operations routine of each worker are depicted in Figure 8.11. Keep in mind that each process means the standard operations routine, or in other words, the walking route of each worker. Such a walking route will not change unless the cycle time of this line is changed.

The manual operations time to complete one unit at each process was about 26 seconds for all workers except at process 8. The job characteristic and fatigue rank of each process in this line are described in Figure 8.12. The grade of fatigue at each process will be different depending on differences of the operations contents.

Job rotation at shop 523 is accomplished in intervals of two hours. First, a predetermined job rotation schedule must be planned for the five days of the following week. When planning this type of schedule, it should be noted that the allocation of the various processes among workers must be fair; also, the training program for the newcomer must be considered.

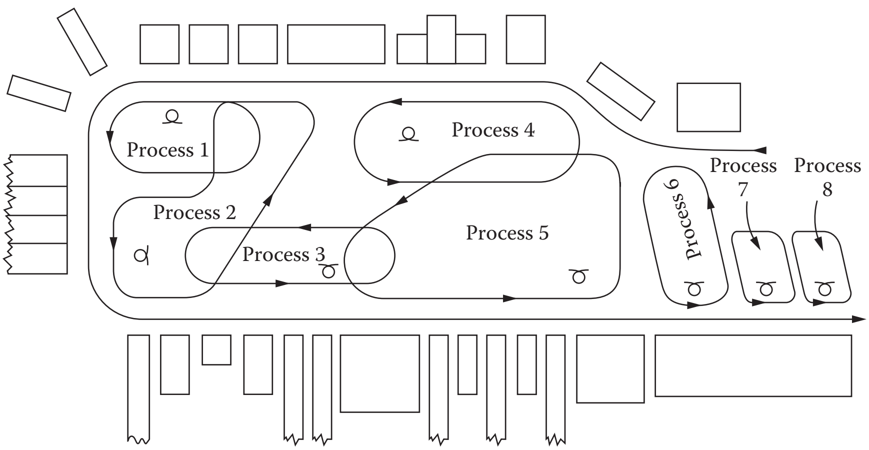


FIGURE 8.11
Layout and standard operation routines.

Process No.	Contents of the job at each process	Characteristic of operations	Manual operations time	Fatigue rank
1	Differential case	Skill of finger work is required	26"	4
2	Cover assembly	Skill and knowledge of quality check are required	26"	5
3	Can adjust	Long walking distance	26"	3
4	Ring gear assembly	Finger work, and heavy work by right arm	26"	1
5	Pre-load adjustment	Long walking distance with heavy material	26"	2
6	Bearing assembly	Sensitivity of hand and finger is required	26"	6
7	Back-rush holding	Skilled work, and heavy work by waist and arms	26"	7
8	Rock-bolt assembly	Waiting time of 2 sec. exists	24"	8

FIGURE 8.12
Job characteristics and fatigue rank of each process.

Job–Rotation Schedule (shop no. 523)

Times of rotation	Line name / Time interval / Process no.	160 mm differential carrier assembly line							
		1	2	3	4	5	6	7	8
1	8AM–10AM	A	B	C	D	E	F	G	H
2	10AM–12AM	G	A	B	C	D	H	E	F
3	1PM–3PM	E	G	C	A	B	F	D	H
4	3PM–5PM	D	C	G	B	A	H	F	E
5	5PM–7PM	B	D	C	E	E	A	G	H

FIGURE 8.13
Job rotation schedule for workers (A–H).

Each morning, the general foreman listens again to the health conditions and desires of all workers, and also reexamines the proper way to introduce extra workers onto the line. Finally, he determines the job rotation schedule (Figure 8.13).

In this job rotation schedule, the following conditions of the workers H, B, and C should be considered:

- Worker H is a veteran, but sickly.
- Worker C is a long-term extra worker from outside of the company.
- Worker B is still in a training stage for process 1.

Therefore, when worker B works at process 1 in his fifth rotation time, veteran worker D will support him as a nearby worker.

At this shop, all workers except C and H will engage in different kinds of jobs in each two-hour interval. Since this workshop has a smaller cycle time (twenty-six seconds), the worker must have a narrower range of jobs; this is the principal reason for assigning a two-hour interval to this shop. In the event the cycle time was longer, however, workers could handle a wider range of jobs, and thus a four-hour interval could be applied. Some shops even have eight-hour intervals (or, one-day interval).

Additional Advantages of Job Rotation

Among the advantages of job rotation documented by Toyota at their Tsutsumi Plant include the following:

- The workers' attitudes are refreshed and muscle fatigue can be prevented; as a result, workers are more attentive and careful in avoiding labor accidents. The frequency of shop accidents is actually decreasing at this plant.
- The feeling of unfairness that veterans must have heavy work will disappear. Also, at the beginning of each rotation, there is conversation between rotating workers. Through these conversations, the human relationship between workers improves, and the mutual relief movement will be further promoted.
- Since senior workers and supervisors teach their own skills and knowledge to their younger workers and subordinates, the skills and know-how are dispersed throughout the shop and kept on standard operations sheets.
- Since each worker participates in every process within the shop, he feels responsible for all goals of the shop, such as safety, quality, cost, and also production quantity.
- At new shops and processes, all people (irrespective of supervisors or subordinate workers) take a fresh approach and, through this new viewpoint, can isolate problems or points for improvements. Thus, ideas and suggestions to improve the process will increase remarkably.

The various benefits can best be summarized with the simple words *respect for humans*. This is a considerably different attitude from traditional schemes where mass production yields a division of labor and, in turn, specialization of labor, simplification of jobs, and, finally, human alienation.

Importance of the Line Chief: Giving Rest Time and Job Rotation to Workers

One of the most important elements affecting the success of the job rotation system is the role of the line chief. Aside from guidance, the line chief also allows workers to take rest time while still permitting job rotation. The line chief or foreman can always replace a worker in the line, whether the worker is taking a rest or exchanging jobs with another worker.

Suppose worker A wishes to take a rest (or another kind of job). At this time, he calls his line chief or foreman and explains his desire. The line chief will then take worker A's job, and worker A can take a rest. After taking a rest, worker A may go to worker B and ask to exchange jobs. Worker B then leaves his process and worker A engages in B's job. If worker B does not want to have a rest, he may request to change jobs with another worker. The other worker can in turn take a rest when worker B takes his new job.

In this way any worker can take a rest and still exchange his job with another worker. This process can occur quite freely whenever a worker desires, even though the job rotation schedule (Figure 8.13) has been established and there is no allowance for a rest time in the standard operations routine sheet.

9

One-Piece Production in Practice

§ 1 REQUIREMENTS FOR ONE-PIECE PRODUCTION

In the JIT system, the concept of having things flow smoothly through the factory one by one, like water, without any holdups, is termed *one-piece production* or *single-unit production*. As explained in Chapter 7, one-piece production is a system in which the work is passed down the line one unit at a time within the takt time, following the product's processing sequence, with production synchronized between each process and the next.

To achieve such a system, the workers in the factory cannot simply be single-skilled operators each responsible for a single process; they must be multi-skilled operators, each of whom can operate several different processes. Sometimes, when attempts are made to introduce JIT into a factory, the workers object to the idea of working standing up and learning multiple skills. However, along with "autonomation," these are the three essential requirements for one-piece flow:

1. **Working standing up**: in order to manage multiple processes, the workers have to work standing up.
2. **Multi-process handling by multi-skilled workers**: since multi-process handling means operating several different machines, the workers have to be multi-skilled.
3. **Autonomation:** this means autonomation in the sense of decoupling the workers from their machines.

These three challenges must be overcome when introducing multi-process handling, and the best way of doing so is not to try to achieve perfection all at once but to work on the principle that a 50 percent improvement is better than none at all. This is the idea of improving continually, one step at a time.

This chapter describes what needs to be done to actually introduce the production systems required for one-piece flow into a factory, explaining concepts such as working standing up, multi-process handling, autonomation, cell lines, attaching castors, and smoothed production.

§ 2 RESISTANCE TO WORKING STANDING UP

Let us assume that a factory has selected “Product Series A Assembly Line” as its pilot line in its drive toward one-piece flow. At the morning meeting on the first day of the improvement campaign, the operations manager stands in front of the line’s workers and announces that they will no longer be sitting down to work but will from now on work standing up.

Some labor unions might object to this, claiming that such a change would make the workers’ jobs more demanding. They could say that telling the workers to work standing up should not be treated as a management directive but as a change in working conditions, and should therefore be brought up in a work council meeting and thoroughly discussed on a level playing field between management and union representatives.

If this happens, the operations manager should explain carefully why it is necessary to switch to working standing up.

Necessity No. 1: On an assembly line, it is quite difficult to share the workload equally between all the workers. Some are always rushing to keep up with the pace of the line, while others always seem to have extra time. In other words, it is hard to balance the line. In such a situation, an overlap zone can be established between neighboring operators, rather like the baton handover zone in a relay race. When the workers are working standing up, they can move in and out of this overlap zone freely to help each other out, which in fact makes their jobs easier.

Necessity No. 2: The following explanation can also be given: many of us work in factories sitting down, but when at home in our kitchens we work standing up as a matter of course. The fact that the necessary series of tasks for making a stew—for example, washing and cutting up the vegetables, cutting up the meat, putting the ingredients in a pot and stewing them, adding seasoning, setting the table, serving the meal, and so on—are all done standing up makes the work go smoothly. Since each of the tasks involved in cooking a meal requires a different skill, this is also an example of multi-process handling. When cooking a meal at home, we are in fact practicing one-piece flow, carrying out multiple processes with absolutely no wasteful holdups between them. In this way, working standing up is a fundamental prerequisite at the heart of the Toyota Production System, leading to multi-process handling and one-piece flow.

Necessity No. 3: Experience has in fact shown that working standing up enables the waste and strain in individual workloads that is attributable to poor line balancing to be eliminated, resulting in vastly better productivity (defined here as "the quantity that each operator can produce during normal working hours in one day"). This is also called *per-capita output*. The quantity produced by each operator per hour can also be measured. Since the per-capita output is *the working efficiency of each operator, equivalent to their "instantaneous windspeed,"* it is unrelated to sales and is increased by working standing up.

It is certainly true that workers may feel more tired for the first one or two weeks after switching from working sitting down to working standing up, until they get used to it, but once they get over this, they find many benefits. For example, some say that moving around more is good exercise and makes them feel healthier, while others say that their posture has improved. Also, since neighboring workers can help each other out, it becomes easier for them to match their workrate to the pace of the line.

Since working standing up is done to eliminate waste due to incompatibilities in balancing the line and to make the work more effective (which is the starting point of the Toyota Production System), it does not result in intensifying the work. If any problems emerge when it is introduced, then further improvements should be made to eliminate them. Managers and supervisors should join with the operators in making improvements and solving problems. This is then bound to inspire the front-line workers to raise their work capacity (i.e., productivity) further and get everyone working together to keep their company profitable.

Not a few companies found that when they tried to introduce the Toyota Production System, their employees refused to accept working standing up. As a result, these companies were unable to make any progress and their attempts to introduce the system failed.

§ 3 RESISTANCE TO MULTI-SKILLING

The next step is multi-process handling. Although this can be applied to assembly lines as well, this chapter focuses on explaining how to introduce it into machining lines (i.e., the processes just prior to assembly).

The first step in multi-process handling consists of each worker learning how to do some of the tasks performed in the processes immediately before or after his or her own process, making it possible for workers to assist each other in the baton-passing zone described earlier.

However, if a department manager suddenly announces one day to all the workers in a machining shop that the existing arrangement of machines in groups of the same model is to be replaced by multi-process lines dedicated to particular components, and that everyone will then be expected to operate all the processes needed to produce a particular component, he or she is likely to encounter some resistance. This is because the workers are used to specializing in a particular operation—lathe operators may have done nothing but operate lathes for decades, for example, and boring machine operators may have done nothing but bore holes. They have mastered the art of their particular operation, and have pride and confidence in their professional skills.

It is therefore best not to try to achieve complete multi-skilling overnight but to have the operators learn to operate different machines little by little, and spend one or two months gradually increasing the range of operations that each operator is expected to cope with.

To alleviate discontent and resistance, the need for multi-process handling should be carefully explained. The workers should be told that a system in which a fixed quantity of items is made regularly every month, no matter how well they are made, no longer meets customers' needs. The market has changed and now demands a large variety of products in small quantities rather than large quantities of only a few different types. Companies are now required to produce only what can be sold, when it can be sold, in the quantity that can be sold. One-piece production, achieved by means of multi-process handling, makes this possible. The type of system required is one that, for example, can respond swiftly to changes in the sales forecast ratios among different products in the middle of the month.

§ 4 BARRIERS TO AUTONOMATION

To make multi-process handling possible, each operator, after setting a workpiece on a machine and pressing the switch, has to be able to leave that machine to do its job and move on to the next machine. This means that machines have to be able to carry out their processing tasks automatically and switch themselves off when they have finished. At Toyota, this type of automation is called *autonomation* or *automation with human intelligence*.

This kind of automation is indispensable for multi-process handling, which begins with the workers improving their own skills, but ultimately requires the machines themselves to be improved. It is therefore wrong to think that workplace improvements under the Toyota Production System consist only of improvements to working methods, and that the production engineering department (the department responsible for installing the machines) has no role to play.

The help of the production engineering department is needed in order to achieve autonomation, and the first thing they need to do is to devise mechanisms for making the machines stop by themselves when they have finished each automated processing task. The second thing they need to do is to devise mechanisms for making the machines stop automatically if anything goes wrong while they are performing a task. The aim of the first of these is to decouple the operators from their machines and raise productivity, while the aim of the second is to assure quality.

Autonomation is the first requirement for one-piece flow, but like multi-process handling, it also takes time. Thus, although the layout for multi-process handling could be done all in one go, the new way of working should actually be introduced gradually to enable the operators to cope with the transition.

How to Achieve Autonomation (in the Sense of Decoupling Operators from Their Machines)

Autonomation will be explained by taking as an example a bench-top boring machine (a typical machine tool). This type of machine can be seen not only in factories but also in all kinds of offices; one example is the electric hole-punching machine shown in Figure 9.1 (1), which is used to make two holes in the left-hand side of a stack of documents in order to file them in a binder.

With an electric boring machine such as that shown in Figure 9.1, the only movement produced automatically by the electric motor when someone presses the switch at the bottom right is the *rotary motion of the drill* (the cutting tool) for cutting the holes in the paper. To autonomate the process, it would therefore be necessary to automate the *cutting-in (feed)*

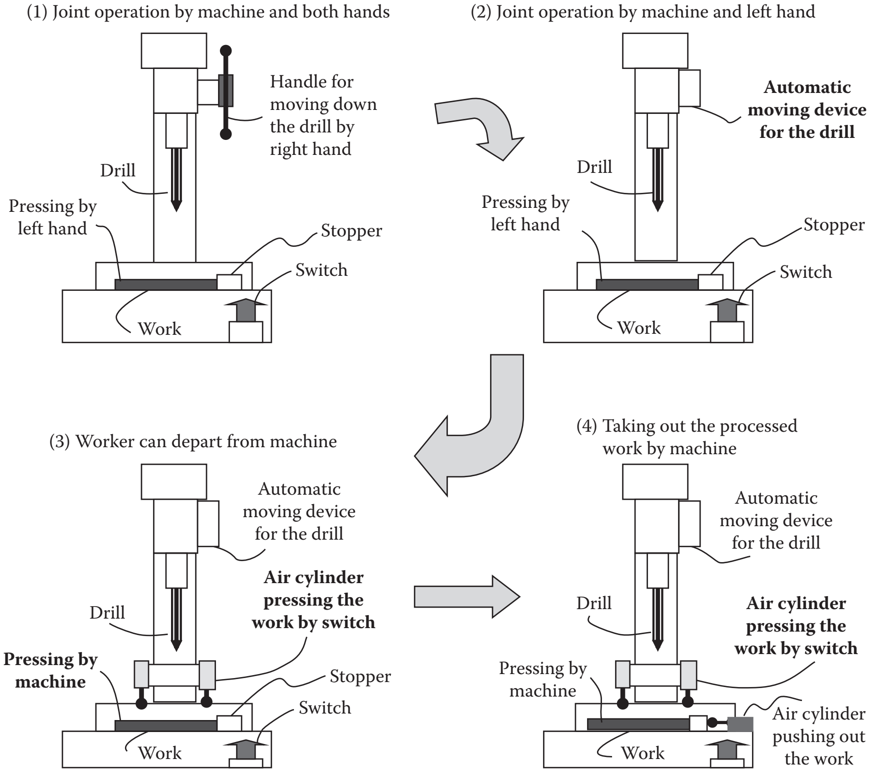


FIGURE 9.1
Separation of human operation from machine. (Adapted from Hirano, H. 1989. *100 Q&A for JIT Introduction*, Nikkan Kogyo Shinbun, p. 69, with partial revision.)

motion whereby the drill is moved down in the direction of the paper (the workpiece), which is currently done by the user lowering the handle with his or her right hand. Additionally, since the paper is liable to move around while the holes are being cut (which would cause the holes to become misaligned), even if placed firmly against the guides to begin with, the user has to perform a *restraining action* by pressing on the stack with his or her left hand to keep it in place.

All this means that the following improvements are needed to release the user from having to attend to the boring machine while it is operating:

First, the *cutting-in (feed) motion* whereby the drill moves down in the direction of the paper has to be automated, so that, when the "on" switch is pressed, the drill descends and cuts the holes in the paper automatically. This would make it unnecessary for the user to operate the handle with his or her right hand (see Figure 9.1 [2]).

Next, to make it unnecessary for the user to hold the stack in place with his or her left hand, the *restraining action* has to be automated by installing a device that does this by means of a pneumatic cylinder. This device should actuate automatically when the switch is pressed (see Figure 9.1 [3]).

Making these improvements would free up both of the operator's hands from having to be on the machine while it is working. The only tasks left to do within each cycle would be to remove the workpiece that had been placed on the machine in the previous cycle, set the next workpiece on the machine, and press the switch. These improvements alone would enable the operator to move straight to the next machine after setting the workpiece on the first machine and pressing the switch, making multi-process handling possible. (Precisely speaking, this kind of autonomation—decoupling the operator from the machine—is needed for multi-machine handling as well as for multi-process handling).

To take the automation a stage further, the following additional improvements would be needed:

1. ***Automate the removal of the workpiece after processing.*** Install a pneumatic device that automatically pushes the workpiece out of the machine after it has been processed (see Figure 9.1 [4]).
2. ***Automate the setting of the workpiece on the machine.***
3. ***Autonomate the machine so that it stops whenever a defective product is produced.***

Performing all these improvements would make it possible to achieve completely unattended production.

§ 5 ATTACHING CASTORS

The production engineering department also has a role to play in attaching castors (small wheels) to the bases of the machines to make them easily movable at any time in response to requirements. This is a prerequisite for changing the layout of the machines from the conventional group layout (by machine type) to a layout in line with the flow of products (also known as a *flow shop layout*). In fact, this is a prerequisite for one-piece flow and is the first thing that ought to be done.

Shop-floor improvements in the Toyota Production System are thus not limited to improvements in working methods; they also include making whatever machine modifications are needed to achieve the type of autonomation that allows the operators to leave their machines, starting with welding castors onto the machine's bases. In fact, the number of hardware improvements needed is not inconsiderable. This means that, although introducing TPS does not require a huge investment, some of it does require a certain amount of additional expenditure.

§ 6 SMOOTHED PRODUCTION

Process-sequenced production (moving materials continuously in the order of the processes they are subjected to) implies multi-process handling. In order to achieve synchronization between the different processes on a process-sequenced line, separate lines each dedicated to making a particular item are usually set up, and these are called *cell lines* or just *cells*. The whole system is called *cellular manufacturing*.

When a large variety of different models is being made, however, setting up cell lines with each cell dedicated to producing a particular item can result in having too many cells, with more machines needed than for a job-shop layout producing the same variety of items. In this case, the final assembly line must be set up as a mixed-model line, and the production must be "smoothed" (i.e., each model is assembled one unit at a time and comes off the line on every beat of the takt time). This enables the number of production lines installed to be minimized and improves the investment efficiency.

In other words, the number of cells can be minimized by ensuring that smoothed production is carried out, in the third of the following three stages of mixed-model assembly:

1. Produce in sequence, lumping the total quantity of each model needed each month together.
2. Produce in sequence, lumping the average quantity of each model needed each day together.
3. Produce each model one unit at a time, matching the pace to the takt time of each model.

Also, if the number of subassemblies assembled on the lines upstream of a mixed-model assembly line of this type (the subassembly lines) is large, setting up dedicated one-piece flow lines for each different product model can also impair investment efficiency. In this case, the subassemblies (e.g., an item T that is attached to the final product) are produced one at a time on the subassembly line in the same sequence (Ta, Tb, Tc, and so on) as the products are assembled on the final assembly line (A, B, C, and so on).

§ 7 AN EXAMPLE OF IMPROVEMENT FOR ONE-PIECE FLOW: A FACTORY PRODUCING CABINETS FOR USE AS FLAT-SCREEN TELEVISION STANDS

Since the production system for making flat-screen television stands is quite simple, one-piece flow can be achieved by rearranging the machine layouts almost entirely in accordance with the textbook rules of TPS.

In the days when this factory had its machines laid out in groups of the same type, there was a considerable amount of work-in-progress (WIP) inventory at each group of machines. The factory therefore changed the arrangement of machines and workbenches to one grouped by the item being made rather than by the type of machine; in other words, it changed to an arrangement of U-shaped lines, or cell lines, such as a line where the doors (one of the subassemblies for the TV cabinet stands) are attached and processed, and a line where the wood is trimmed.

They also turned the line where the TV cabinet stands are finally assembled into a one-piece flow line conforming to the takt time of each product model. In conjunction with this, they matched the takt time of the cabinet door assembly line to the takt time of the final assembly line and made it possible to make one unit of product at a time by coordinating the door models with the product models. In other words, they achieved one-piece flow by means of production smoothing based on synchronizing the final assembly line and the component line. See Figure 9.2.

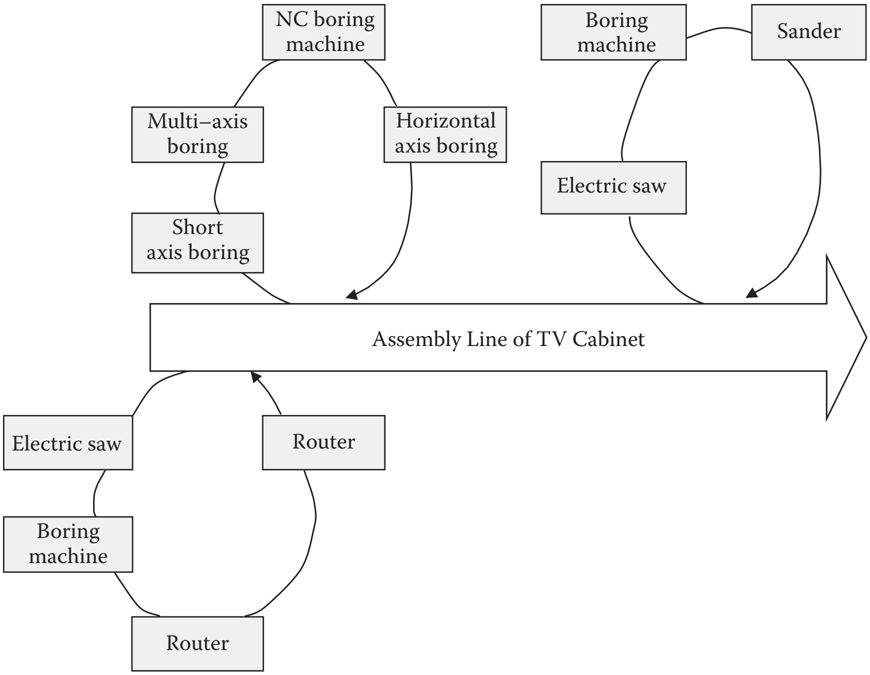


FIGURE 9.2
Example of improved layout: U-shaped multi-process handling in TV cabinet plant.

10

Standard Operations Can Attain Balanced Production with Minimum Labor

§ 1 GOALS AND ELEMENTS OF STANDARD OPERATIONS

The ultimate purpose of the Toyota Production System is to reduce costs relating to production. To do so, Toyota tries to eliminate production inefficiencies such as unnecessary inventories and workers.

Standard operations are aimed at using a minimum number of workers for production. The first goal of standard operations is to achieve high productivity through strenuous work. Strenuous work at Toyota, however, does not mean forcing the workers to work very hard; instead, it means working efficiently without any wasteful motions. A standardized order of the various operations to be performed by each worker, called the *standard operations routine*, is important in facilitating this first goal.

The second goal of Toyota's standard operations is to achieve line balancing among all processes in terms of production timing. In this case, the cycle time concept should be built into standard operations.

The third and final goal is that only the minimum quantity of work-in-process will qualify as *standard quantity of work-in-process*, or the minimum number of units necessary for the standard operations to be performed by workers. This standard quantity helps eliminate excessive in-process inventories.

To attain these three goals, standard operations consists of the cycle time, standard operations routine, and standard quantity of work-in-process (Figure 10.1).

In furthering these goals, production is set to eliminate accidents and defective production. As a result, the routine and positions to check the

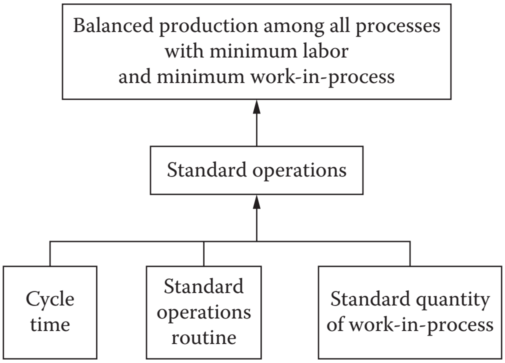


FIGURE 10.1
Elements of standard operations.

safety and quality of products are also standardized. Thus, safety precautions and product quality are subgoals of Toyota's standard operations.

§ 2 DETERMINING THE COMPONENTS OF STANDARD OPERATIONS

The components of standard operations are determined mainly by the foreman (supervisor). The foreman determines the labor hours required to produce one unit at each machine and also the order of various operations to be performed by each worker. Generally in other companies such standard operations are determined by the IE staff.

Toyota's method might seem unscientific; however, the foreman has an intimate knowledge of past performances of workers. In addition, the typical foreman also uses IE techniques, such as time and motion studies; therefore, such factors as the determined motion speed can be regarded as appropriate even by an impartial observer. Also, to teach the worker to understand and follow the standards completely, the foreman himself must master and recognize the standards perfectly.

Standard operations are determined in the following manner:

1. Determine the cycle time.
2. Determine the completion time per unit.
3. Determine the standard operations routine.
4. Determine the standard quantity of work-in-process.
5. Prepare the standard operations sheet.

Determining the Cycle Time

The cycle time or takt is the time span in which one unit of a product must be produced. This cycle time is determined by the required daily quantity of output and the effective daily operating time in the following manner:

$$\text{Cycle Time} = \frac{\text{Effective Daily Operating Time}}{\text{Required Daily Quantity of Output}}$$

The effective daily operating time should not be reduced for any allowances due to machine breakdowns, idle time awaiting materials, rework, or for fatigue and rest time. Also, the necessary quantity of output should not be increased to allow for defective output. By viewing as unnecessary the time spent in producing defective items, such time is visible when it occurs in a process, making it possible to take immediate action to improve the process. The cycle time can be rather long compared to other companies that make allowances for fatigue time and defective items when determining the cycle time. Moreover, since it is necessary to determine both the number of different operations and the number of workers needed to produce a single unit of output within the cycle time, the number of workers in any department at Toyota's factory can be decreased if the cycle time is relatively longer.

Sometimes, the cycle time is determined erroneously by using the current machine capacity and labor capacity. Although this gives a probable time span for producing one unit of output, it does not give the necessary time span needed for repositioning the workers. To be sure that the cycle time is determined properly, the effective daily operating time and the required daily output must be used.

Determining the Completion Time per Unit

The completion time per unit of output has to be determined at each process and for each part. This time unit is always written on the *part production capacity sheet* that is filled out for each part (Figure 10.2).

The *manual operation time* and the *machine automatic processing time* are both measured by a stopwatch. The manual operation time should not include the walking time at the process. The speed and the level of skill required for each manual operation are determined by the foreman.

Part production capacity sheet	Item no.	Item name	Necessary quantity per day	Worker's name

Order of processes	Description of operations	Machine no.	Basic time: Manual operation time (min.)	Manual operation time (sec.)	Machine processing time (min.)	Machine processing time (sec.)	Completion time per unit (min.)	Completion time per unit (sec.)	Tool's exchange: Exchange unit	Tool's exchange: Exchange time	Production capacity (960 min)	References: manual operation ———; machine processing ·········
1	Center dirll	CD-300		07	1	20	1	27	80	1'00"	Units 655	
2	Chamfer	KA-350		09	1	35	1	44	20	30"	549	
									50	30"		
3	Ream	KB-400		09	1	25	1	34	20	30"	606	
									40	30"		
4	Ream	KC-450		10	1	18	1	28	20	30"	643	
2-1	Mill	MS-100		(20)	(2	10)	(2	20)	1,000	7'00"	820	10" 10" 2'10"
2-2	Mill	MS-101		(15)	(2	10)	(2	15)	1,000	7'00"		5" 10" 2'10"
	(two stands of machines)			18								[manual operation time per unit] $= \frac{20" + 15"}{2} = 17.5" \rightarrow 18"$
3	Bore	BA-235		(08)		(50)		(58)	500	5'00"	1,947	
	(two units processing at a time)			04				29				[manual operation time per unit] $= \frac{8"}{2} = 4"$
4	Gauge (1/5)			(18)								
	(one unit inspection in every five units)			09								[manual operation time per unit] $= \frac{18"}{2} = 9"$
			Total									

FIGURE 10.2
Part production capacity sheet.

The *completion time per unit* in the basic time column is the time required for a single unit to be processed. If two units are processed simultaneously, or one unit in every few units is inspected for quality control, the completion time per unit will be written in the reference column.

In the tool exchange column, the *exchange units* specify the number of units to be produced before changing the bite or tool. The *exchange time* refers to the setup time.

The production capacity in the extreme right-hand column is computed by the following formula:

$$N = \frac{T}{C+m}, \text{ or } \frac{T-mN}{C},$$

where mN = summation of total setup time

Formula Notations:
N = Production capacity in terms of units of output
C = Completion time per unit
m = Setup time per unit
T = Total operation time

Determining the Standard Operations Routine

After determining the cycle time and the manual operation time per unit for each operation, the number of different operations that each worker should be assigned must be calculated. In other words, the standard operations routine of each individual worker must be determined.

The *standard operations routine* is the order of actions that each worker must perform within a given cycle time. This routine serves two purposes. First, it provides the worker with the order or routine to pick up work, put it on the machine, and detach it after processing. Second, it gives the sequence of operations that the multi-functioned worker must perform at various machines within a cycle time.

At this point, it is important to differentiate between the order of process and the operations routine because these two orders are not identical in many cases. If the operations routine is simple, it can be determined directly from the part production capacity sheet (Figure 10.2). In this case, the order of processes is actually identical with the operations routine. If the routine is complicated, however, it may not be easy to determine whether the automatic processing time of a certain machine will be finished before the worker handles the same machine in the next cycle of the takt time. As a result, the standard operations routine sheet is used to determine the exact operations routine (Figure 10.3).

The procedure to prepare the standard operations routine sheet follows:

1. The cycle time is drawn with a red line on the operations time dimension of the sheet.
2. The approximate range of processes which one worker can handle should be predetermined. The total operations time, which is approximately equal to the cycle time in red, should be computed using the part production capacity sheet (Figure 10.2). Some slack time for walking between machines must be allowed. The walking time should be measured using a stopwatch and recorded on some memo.
3. The manual operation and machine processing times for the first machine are first drawn on this sheet by copying the data from the part production capacity sheet.
4. Next, the second operation of this worker must be determined. It should be remembered that the order of processes is not necessarily identical to the operations routine. Also, the walking distance between machines, the point at which product quality is checked, and specific safety precautions must be taken into account at this stage. If some walking time is necessary, its time must be drawn on the sheet by a wavy line from the ending point of the preceding manual operation time to the beginning point of the subsequent manual operation time.
5. Steps 3 and 4 are repeated until the whole operations routine can be determined. When performing these steps, if the dotted line of machine processing time reaches the solid line of the next manual operation, the operations sequence is not feasible and some other sequence must be chosen.
6. Since the operations routine was plotted to cover all of the estimated number of processes at step 2, the routine must be completed at the initial operation of the next cycle. If walking time is necessary for this winding up, a wavy line must be drawn.
7. If the final wind-up point meets the red line of cycle time, the operations routine is an appropriate mix. If the final operation ends before the cycle time line, consider whether more operations can be added.

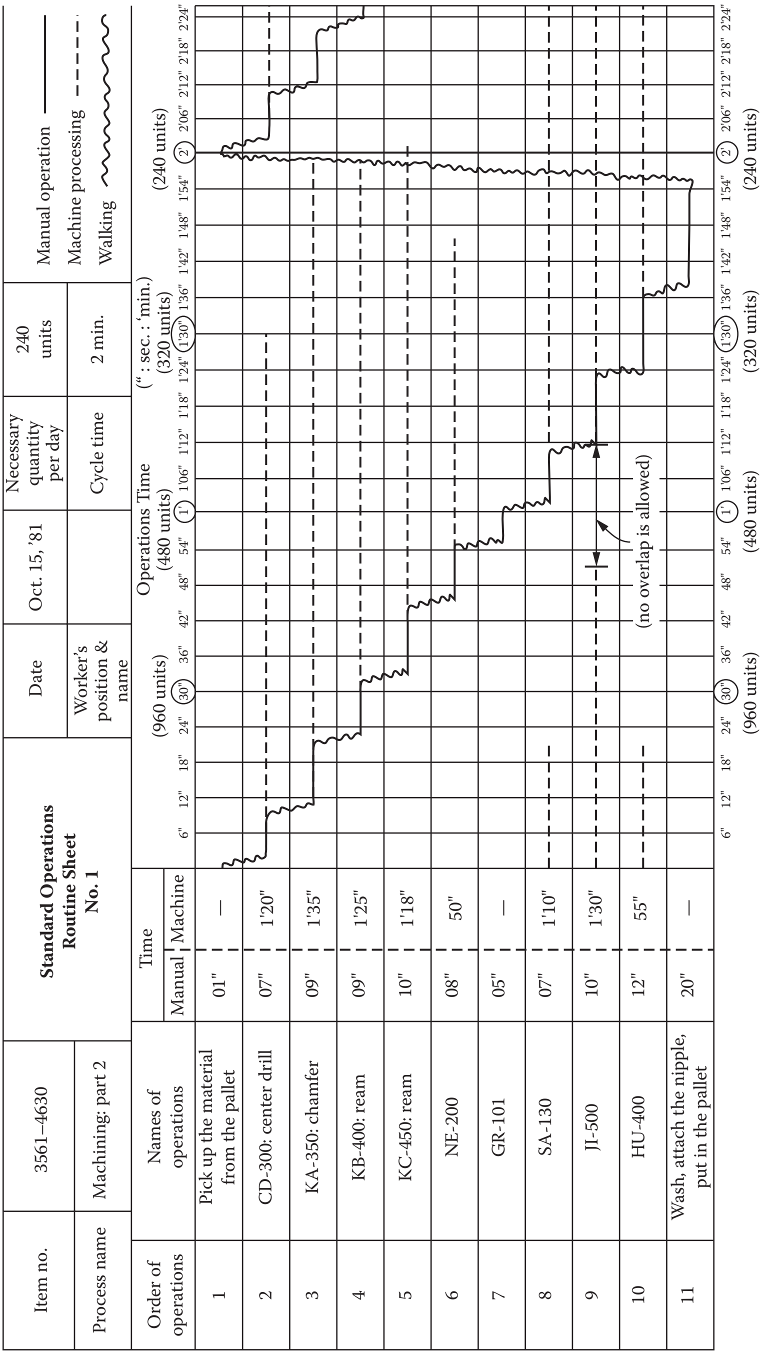


FIGURE 10.3
Standard operations routine sheet.

If the final operation overflows the cycle time line, ways to shorten the overflow must be considered. This could be achieved by improving various operations of this worker.

8. Finally, the foreman should actually try to perform the final standard operations routine. If the foreman can comfortably finish it within the cycle time, the routine can then be taught to the workers.

The allocations of various operations among workers must be such that each worker can finish all of his assigned operations within the specified cycle time. Also, the layout of processes must be such that each worker has the same cycle so that production line balancing among various processes can be realized. A simplified scheme of this allocation of operations and layout of processes is shown in Figure 10.4.

If there is too much waiting time at the end of the operations routine in Figure 10.3, a double cycle time could be set in order to have simultaneous operations by two or three workers subject to the same operations routine. This helps to eliminate slack in the cycle time (Figure 10.5). Otherwise, by an improvement in the operations of the process in question, one more operation could be inserted into the cycle time.

Yo-i-don System

"Yo-i-don" means *ready, set, go*. The Yo-i-don system is a method for balancing the production timing (synchronization) among various processes where there is no conveyor belt. It can also be used as a method of measuring the production capacity of each process.

Let's examine in detail the Yo-i-don system using andon. In a body welding plant of Daihatsu Motor Company (a partner of Toyota), there are six *underbody* processes (U_1, U_2, … U_6), six *side-body* processes (S_1, S_2, …, S_6), and four *main-body* processes (M_1, M_2, … M_4), as depicted in Figure 10.6. By companies, the body welding plant is also called a sheet-metal factory, a body assembly line, or simply a body line.

The body welding plant must produce one unit of its product in three minutes, thirty-five seconds (the cycle time of this factory). By dividing this cycle time into three equal portions accumulatively as 1/3, 2/3, and 3/3 when time elapses, the standard time per unit of a product for completing each process is established. The table in Figure 10.7 is called *andon*; it is hung high from the factory ceiling for all workers to see.

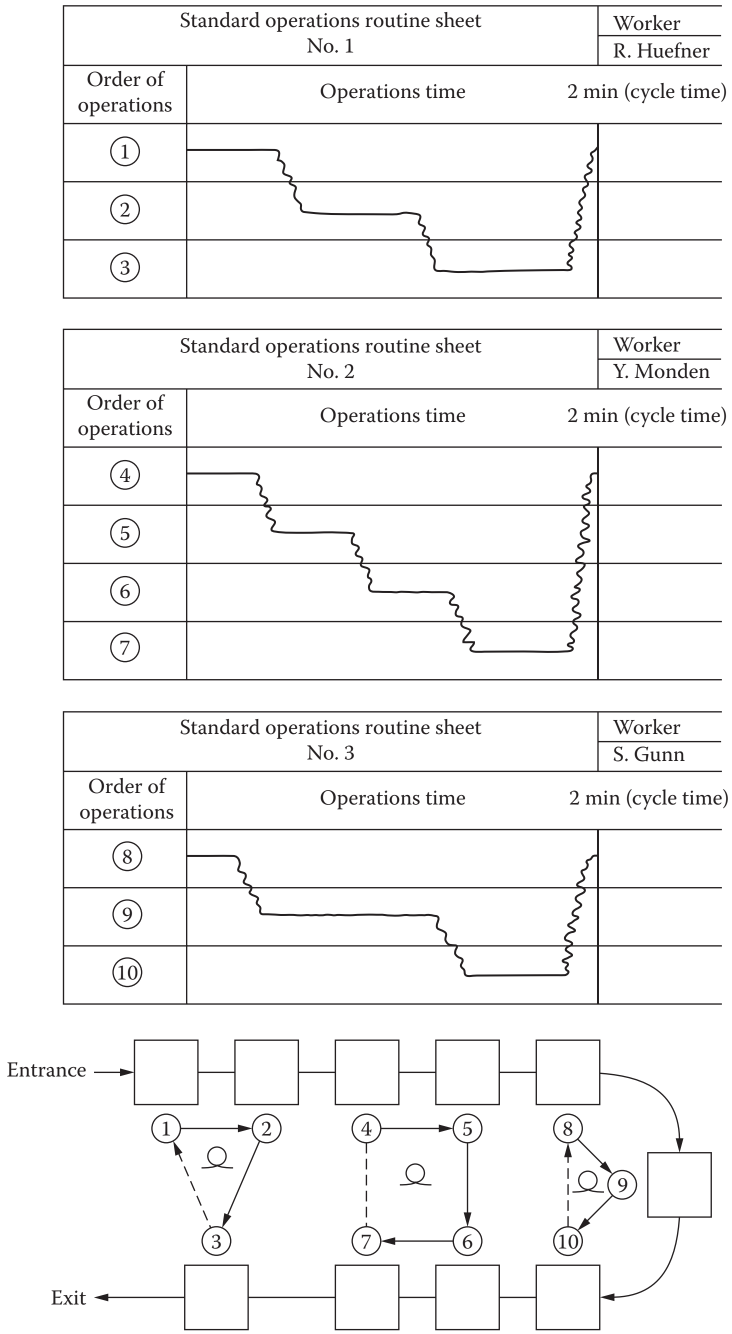


FIGURE 10.4
Allocation of operations and layout of processes.

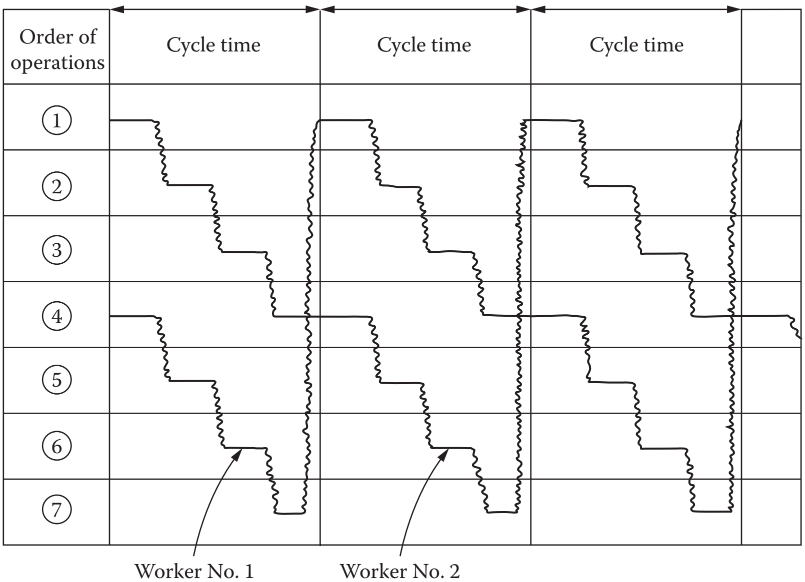


FIGURE 10.5
Double cycle time for use by two workers.

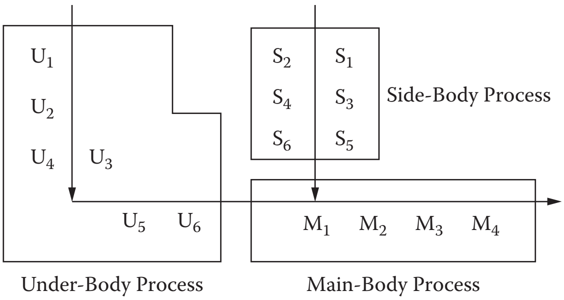


FIGURE 10.6
Process in a body welding plant.

The workers of under-body processes must complete their operations from U_1 to U_6 within three minutes, thirty-five seconds, and the laborers of the side-body processes also must finish their jobs from S_1 to S_6 within this time period. And, the workers in the main-body processes must complete their processes from M_1 through M_4 within the cycle time. At the starting point of a cycle, each worker sets the work to the first process he must handle. If each worker finishes his operations at all his responsible

1/3		2/3		3/3	
U_1	U_2	U_3	U_4	U_5	U_6
S_1	S_2	S_3	S_4	S_5	S_6
M_1	M_2		M_3	M_4	

FIGURE 10.7
Andon of the body plant.

processes and transfers the finished work to the next process within the cycle time, then this body welding plant as a whole can produce one unit of finished product per three minutes, thirty-five seconds.

The worker in each process will push his button when his job is finished, and after three minutes, thirty-five seconds have passed, the red lamp on andon will only go on automatically at those processes where the job is not yet completed. Since the red lamp indicates a delay in processing, the whole line stops operation while a red lamp is on.

For example, the red lamp might be turned on at processes U_4, S_5, and M_2. When this happens, the supervisor or nearby workers help the workers at these processes finish up their jobs. In most cases, all red lamps will go out within 10 seconds.

At this stage, the next cycle time will start, and again the operations in all processes start together. This is called Yo-i-don, which will realize balanced production among all processes. It utilizes andon, cycle time, and multi-process handling for one-piece production and conveyance. The andon in this case is also called the *process-completion display board*, which is at times apart from the usual andon board at Toyota.

In a sense, the Yo-i-don system is a modification of the so-called takt system. Under the ordinary takt system, the supervisor will oversee the whole process, and when all workers finish their respective jobs, he signals to move the product of each process to the next process. However, under the Yo-i-don system at Toyota, such a function is replaced by the andon. However, new considerations and expectations must be made for the introduction of welding robots, conveyor belts between processes, and central computer systems controlling the body-welding lines.

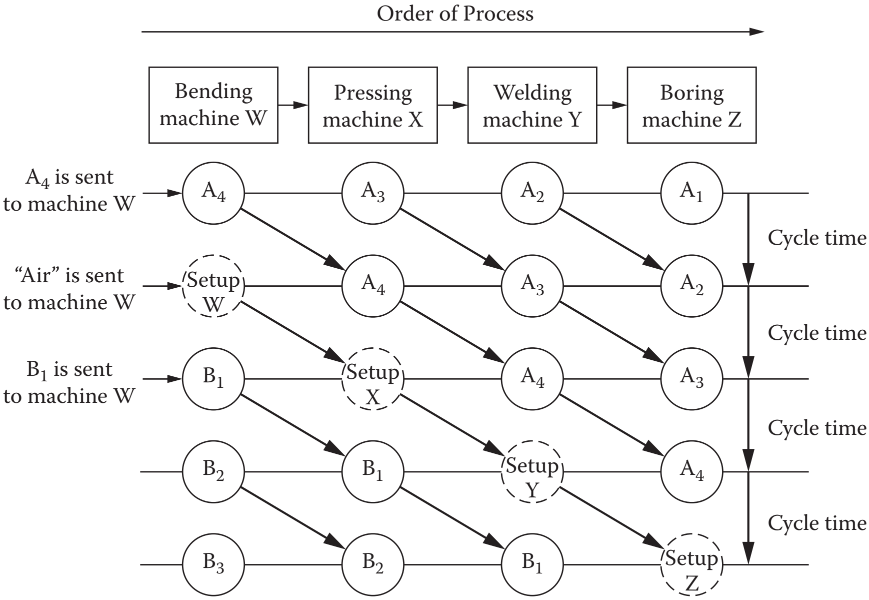


FIGURE 10.8
One-shot setup.

One-Shot Setup

Machine sequencing is an important consideration in complex operation routines. If there are many different machines laid out in succession, how should the setup problem be handled?

Suppose, for example, that there are four different kinds of machines such as a bending machine *(W)*, a punch press *(X)*, a welding machine *(Y)*, and a boring machine (Z) in succession at a certain machining process (Figure 10.8). Assume that these four machines are handled by a multi-functioned worker and although he is now processing part A, he must next process part B in this multi-machinery process.

To change production from part A to part B in this situation, the worker will never set up these four machines after finishing the processing of all of part A at these machines. Such an approach would consume an appreciable amount of production lead time.

Instead, the worker should begin the setup of part B while part A is still in process. Note that only a single unit of a part can flow through each machine within a cycle time. Therefore, when the last unit of part A has been processed at the first machine W, "air" should be sent to machine W. While "air" is flowing through machine W, the setup action can be performed for this machine. In other words, machine W can be set up within a given cycle time.

As a result, all of these four machines can be set up by sacrificing production of just one piece of part B. If all of these four machines are handled by one multi-functioned worker, all of the machines can be set up within four cycle times. If each machine is handled separately by each different worker, all four machines can be set up in one cycle time of the first case. At Toyota, such a setup approach is called *one-shot setup* (Figure 10.8).

Determining the Standard Quantity of Work-in-Process

The standard quantity of work-in-process is the minimum necessary quantity of work-in-process within the production line; it consists principally of the work laid out and held between machines. It also includes the work attached to each machine. However, the inventory at the store of completed products of the line cannot be regarded as the standard holding quantity.

Without this quantity of work, the predetermined rhythmic operations of various machines in this line cannot be achieved. The actual standard holding quantity varies according to the following differences in machine layouts and operations routines:

- If the operations routine is in accordance with the order of process flow, only the work attached to each machine is necessary; it will not be necessary to hold work between machines. (Consider 7 → 8 in Figure 10.9.)
- However, if the operations routine is in an opposite direction to the order of processing, it must be necessary to hold at least one piece of work between machines. (Consider 8 → 7 in Figure 10.9.)

Moreover, when determining the standard quantity of work held, the following points should also be taken into consideration:

- The quantity necessary for checking the product quality at necessary positions of the process
- The quantity necessary to be held until the temperature of a unit from the preceding machine goes down to a certain level

The standard quantity held should be kept as small as possible. Besides reducing holding costs, visual control in checking the product quality and

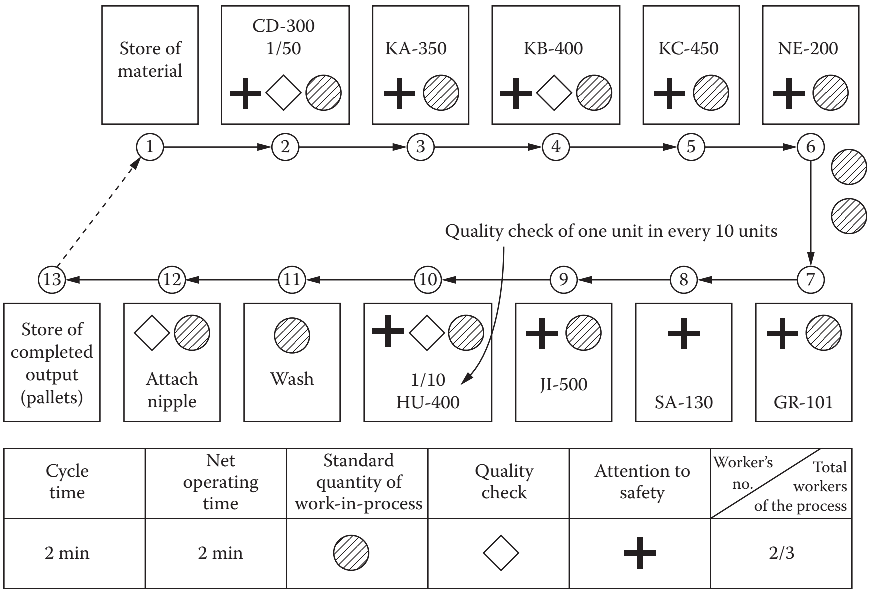


FIGURE 10.9
Standard operations sheet.

improving the process would be made easier because defects would be more evident.

Preparing the Standard Operations Sheet

The standard operations sheet is the final item needed for standardizing the operations at Toyota. This sheet (Figure 10.9) contains the following items:

- Cycle time
- Operations routine
- Standard quantity of work-in-process
- Net operating time
- Positions to check product quality
- Positions to pay attention to worker safety

When a standard operations sheet is displayed where each worker of the process can see it, it can be useful for visual control in the following three areas:

1. It is a guideline for each worker to keep his standardized operations routine.
2. It helps the foreman or supervisor check to be sure each worker is following standard operations.
3. It allows the superior manager to evaluate the supervisor's ability, since standard operations must be revised frequently by improving operations of the process. If the unrevised standard operations sheet was up for a long time, the manager would note that the supervisor is not making an attempt to improve operations.

§ 3 PROPER TRAINING AND FOLLOW-UP: THE KEY TO IMPLEMENTING A SUCCESSFUL SYSTEM

Once the standard operations were set by the supervisor (foreman), he must be able to perform these operations perfectly and then instruct his workers to do so. The supervisor should not only teach the operations but also explain the reasons the standards must be kept (i.e., the goals of standard operations). This provides the workers with the incentive to take responsibility for product quality.

To ensure that the workers thoroughly understand the standards, two sheets called the *operations keypoints note* and the *operations guidance note* are prepared and conveyed to the workers. The operations keypoints note describes the important points of each operation in the standard operations routine, while the operations guidance note will explain the details of each operation at each line and also methods for checking product quality. They also contain the data provided by the standard operations sheet. These sheets are also posted in each process.

The supervisor must always observe firsthand whether the standards are being followed in his department. If the standards are not being kept, he should immediately instruct the workers in the proper procedures. If the standards themselves are faulty, they must be revised promptly.

An electric board shows the actual and scheduled cumulative quantities of outputs at the completion of each cycle time in every process. The supervisor must check the results of implementing the standard operations, and if something abnormal is found in the process, he must investigate the reasons and take remedial actions. The supervisor's remedial actions are regarded as current control or operational control, but his performance in each month can be evaluated by the traditional budgetary control system.

Finally, it is important to revise the standard operations regularly, since they are always imperfect and operations improvements are always required in a process. The most fundamental idea behind the Toyota Production System is summed up in the statement:

> Progress of a company can be achieved only by continuous efforts on the part of *all* members of the company to improve their activities.

11

Reduction of Setup Time— Concepts and Techniques

§ 1 EFFECTS OF SHORTENING THE SETUP TIME

In 1970, Toyota succeeded in shortening the setup time of an 800-ton punch press for the hood and fender to three minutes. This is called a *single setup*, meaning that the setup time has a single-digit number of minutes (within nine minutes, 59 seconds). At present the setup time has, in many cases, been reduced to less than a minute, or *one-touch setup*. Before 1981, American and European companies often spent from two to several hours—or at worst, an entire day—on a setup action.

The need for Toyota to develop such an incredibly short setup time was recognized by Taiichi Ohno, former vice president of the company, who realized that by shortening setup time Toyota could minimize lot size and therefore reduce the stock of finished and intermediate products.

Through small-lot production, the production lead time of various kinds of products can be shortened, and the company can adapt to customer orders and demand changes very promptly. Even if the types of cars and delivery dates are changed in the middle of the month, Toyota can adapt quickly. From this viewpoint, too, the inventory of finished and intermediate products can be reduced.

The ratio of machinery utilization to its full capacity will be increased because of the reduced setup time. It should be noted, however, that the machinery utilization rate is allowed to be low since overproduction is considered to lead to waste, a worse situation than a low utilization rate. The minimization of stocks, job-order oriented production, and prompt adaptability to demand change are the most important advantages of a single setup.

The single setup is an innovative concept invented by the Japanese in the field of industrial engineering. This idea was developed by Shigeo Shingo, a consultant at Toyota, and is now common knowledge in IE theory and practices of the world. The single setup should not be considered a technique. It is a concept that requires a change in attitude by all the people in a factory. In Japanese companies, the shortening of setup time is promoted not by the IE staff, but through the activities of small groups of direct laborers called quality control (QC) circles or ZD (zero defect) groups. Achievement of improved setup time and the attendant morale boost enable workers to take on similar challenges in other areas of the factory; this is an important side benefit of shortening setup time.

§ 2 SETUP CONCEPTS

To shorten the setup time, four major concepts must first be recognized. Six techniques for applying these concepts are described herein. Most of these techniques were devised for applying concepts 2 and 3. To examine each concept and technique, the setup actions for the punch press operation will be used as a main example, but the same approach can be applied to all kinds of machines.

Concept 1: Separate the Internal Setup from the External Setup

Internal setup refers to those setup actions that inevitably require that the machine be stopped. External setup refers to actions that can be taken while the machine is operating. In the case of a punch press, these actions can be taken before or after changing the die.

These two kinds of actions must be rigorously separated. That is, once the machine is stopped, the worker should never depart from it to handle any part of the external setup.

In the external setup, the dies, tools, and materials must be perfectly prepared beside the machine, and any needed repairs to the dies should have been made in advance. In the internal setup, only the removal and setting of dies must be done.

Concept 2: Convert as Much as Possible of the Internal Setup to the External Setup

This is the most important concept regarding the single setup. Examples include the following:

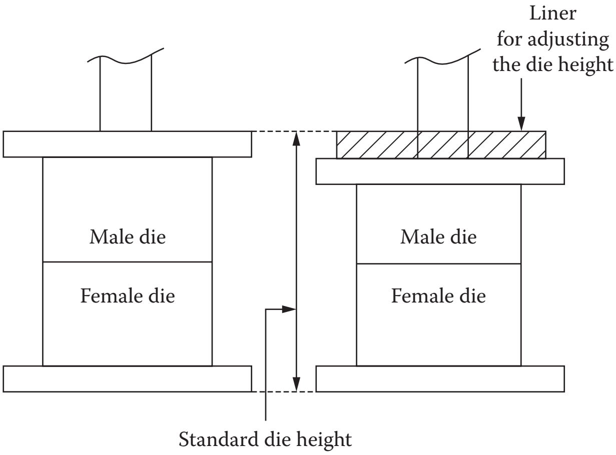


FIGURE 11.1
Using a liner to standardize die height.

- The die heights of a punch press or a molding machine can be standardized by using the liner (spacer) so that stroke adjustment will be unnecessary (Figure 11.1).
- The die-casting machine can be preheated using the waste heat of the furnace that belongs to this machine. This means the trial shot to warm up the metal mold in the die-casting machine can be eliminated.

Concept 3: Eliminate the Adjustment Process

The process of adjustment in the setup actions usually takes about 50 percent to 70 percent of the total internal setup time. Reducing this adjustment time is very important to shortening the total setup time.

Adjustment is usually considered to be essential and to require highly developed skills, but these are mistaken notions. Setting operations such as moving the limit switch from the 100 mm position to the 150 mm position might be necessary. But once the limit switch has been moved to a certain position, further repetitive revision of the setting positions should be eliminated. Setting is a concept that should be considered independently of adjustment. Examples include the following:

- The maker of a punch press may produce a machine that is adjustable to various buyers' die-height requirements. But each particular

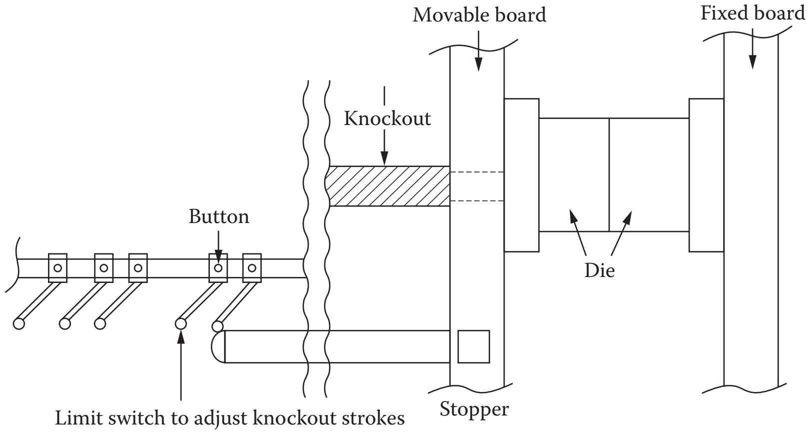


FIGURE 11.2
Installing limit switches at all required positions speeds knockout stroke adjustment.

company (each user) could standardize its die height at a certain size so that the stroking adjustment could be omitted (Figure 11.1)

- Suppose the molding machine requires a different stroke of the knockout depending on the die used, so the position of the limit switch needs changing to adjust the stroke. In order to find the right position, adjustment is always necessary. In such a situation, instead of only the one limit switch, five limit switches can be installed at the five required positions. Furthermore, in the new device, electric current can be made to flow only to the necessary limit switch at a certain point in time with one-touch handling. As a result, the necessity to adjust the position is completely eliminated (Figure 11.2).
- To exchange the dies on the stamping machine, a revolving table car can be prepared. The idea behind this revolving table car is the same as the principle of a revolver (gun). The procedures follow (Figure 11.3):

a. Detach the no. 1 die from the die holder of the press (production by this die is finished).
b. Push the table car to approach the press and then fix the stopper.
c. Put the no. 1 die on the table car.
d. Revolve only the upper part of the table car to set the no. 2 die on to the bolster.
e. Detach the table car stopper, pull the table car far from the press, and at the same time set the no. 2 die on the press.

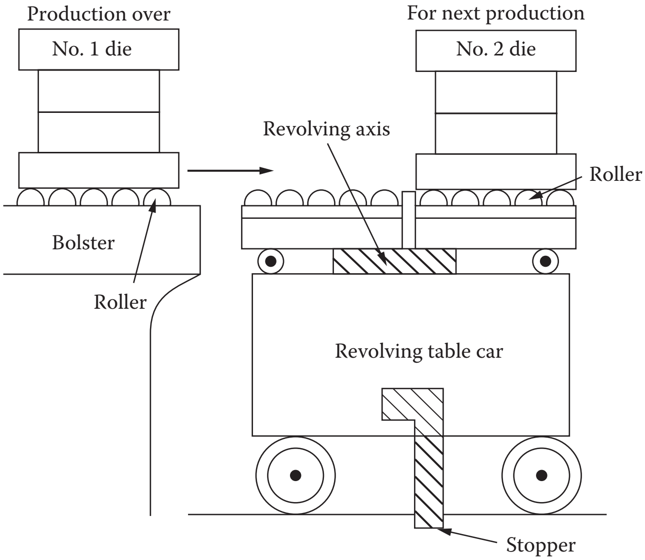


FIGURE 11.3
Revolving table car.

It should again be emphasized that although the machine might be capable of changing positions continuously, only a few finite, stepwise positions are needed. The example of the five discrete limit switches (Figure 11.2) is based on this idea. The number of setting positions needed in actual operations is quite limited. Such a system can be described as the *finite-settings built-in system*. This system will enable one-touch setup.

Concept 4: Abolish the Setup Step Itself

To completely do away with the setup, two approaches can be taken: one, use uniform product design and use the same part for various products; two, produce the various parts at the same time. The latter can be achieved by two methods. The first method is the set system. For example, on the single die of the punch press, two different shapes of parts A and B were carved as a set. These two parts are separated after continuously punching both shapes at the same time.

The second method is to press the multiple parts in parallel using less expensive multiple machines. For example, one department uses a normal jack for a pressing function instead of the punch press. In this department, each worker handles this small jack while he is engaged in other jobs as a multi-functional worker. This jack is attached to a small motor for use and can perform the same function as a heavy punch press. If several jacks of this kind are available, they could be used in parallel for producing various types of parts.

§ 3 CONCEPT APPLICATION

The following are six techniques for applying the four concepts explained before.

Technique 1: Standardize the External Setup Actions

The operations for preparing the dies, tools, and materials should be made into routines and standardized. Such standardized operations should be written on paper and pasted on the wall for workers to see. Then the workers should train themselves to master the routines.

Technique 2: Standardize Only the Necessary Portions of the Machine

If the size and shape of all the dies is completely standardized, the setup time will be shortened tremendously. This, however, would cost a great deal. Therefore, only the portion of the function necessary for setups is standardized. The liner explained under Concept 2 (Figure 11.1) for equalizing the die height is one example of this technique.

If the height of the die-holders were standardized, the exchange of fastening tools and adjustments could be eliminated (Figure 11.4).

Technique 3: Use a Quick Fastener

Usually, a bolt is the most popular fastening tool. But because a bolt fastens at the final turning of the nut and can loosen at the first turn, a convenient fastening tool that would allow only a single turning of the nut should be devised. Some examples are the use of the pear-shaped hole, the U-shaped washer, and the chipped nut and bolt as shown in Figure 11.5.

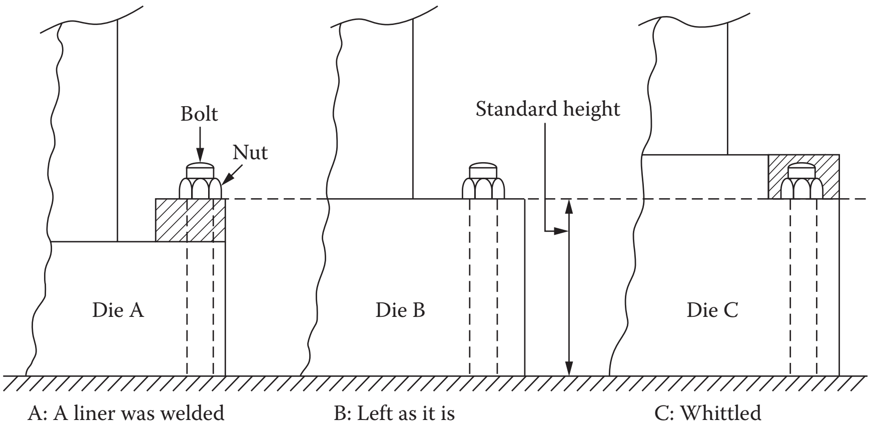


FIGURE 11.4
Standardizing die-holder height reduces the need to exchange fastening tools.

A coil-winding operation was carried out by a certain company. The wound coil used to be pulled out after the nut and washer were removed. To shorten the time required to pull out a coil, the outside diameter of the nut was set at a size smaller than the inside diameter of the coil and a U-shaped washer was used. The coil could then be detached very quickly by loosening the nut by only one turn, pulling out the U-shaped washer, and then pulling out the coil without removing the nut.

There were 12 bolts on the surrounding edge of the furnace. But the bolt hole of the lid was altered to a pear shape, and the U-shaped washer was used. As a result, when the nut is loosened by only one turn, the U-shaped washer should be pulled out and the lid must be turned to the left so that the lid can open through the bigger part of the pear-shaped holes without detaching the nuts from the bolts.

Three portions of the outside of the bolt must be chipped off, and corresponding to these portions, the screw of the nut inside also must be chipped off in three places. Then, when the nut is pushed down by matching the screw portions of the nut to the chipped portions of the bolt, the nut can fasten the machine in only one turn.

A cassette system that utilizes the setting-in idea will enable setup within a minute, or one-touch setup. An example is shown in Figure 11.6. The sliding guide block shown in the figure was also devised and the size of the die holder was standardized. Figure 11.6 also illustrates a device for die installation using a mountain-shaped guide.

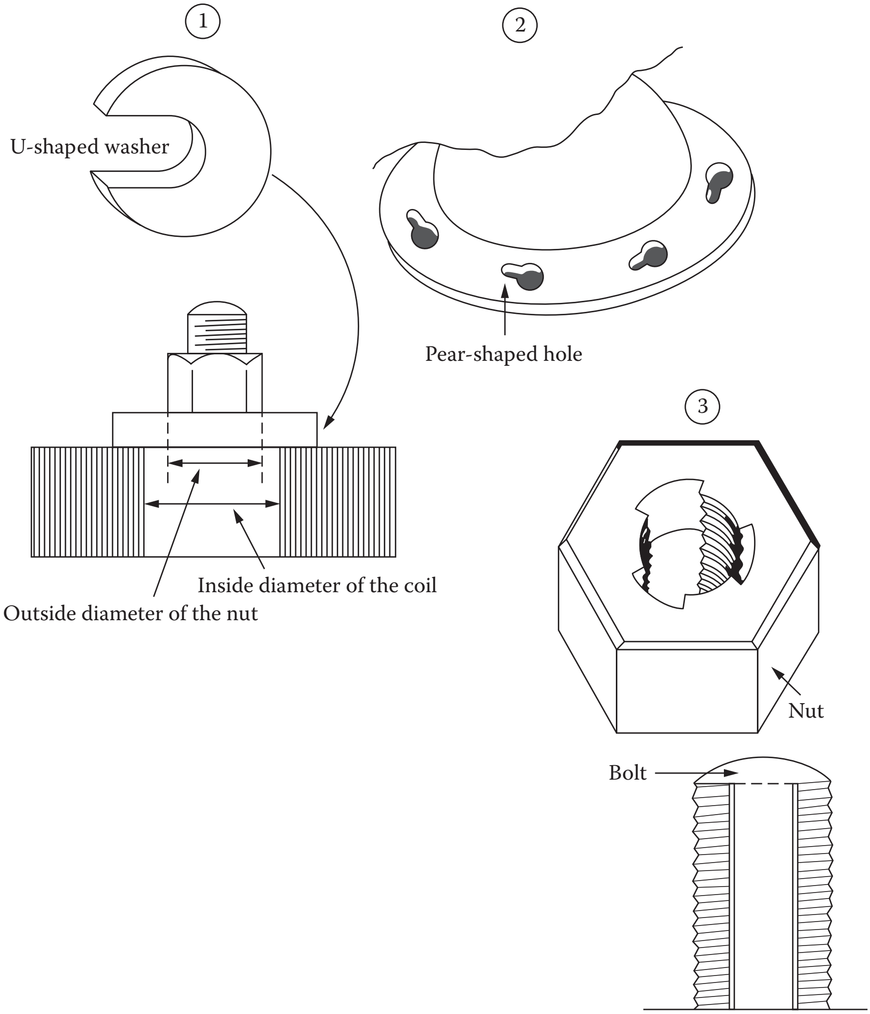


FIGURE 11.5
Examples of quick fasteners (Technique 3): (1) U-shaped washer; (2) pear-shaped bolt hole; (3) nut and bolt with corresponding portions chipped off.

Technique 4: Use a Supplementary Tool

It takes a lot of time to attach a die or a bite directly to the punch press or the chuck of a lathe. Therefore, the die or bites should be attached to the supplementary tool in the external setup phase, and then in the internal setup phase this tool can be set in the machine at one touch. For this method, the supplementary tools must be standardized. The revolving table car in Figure 11.3 is another example of this technique.

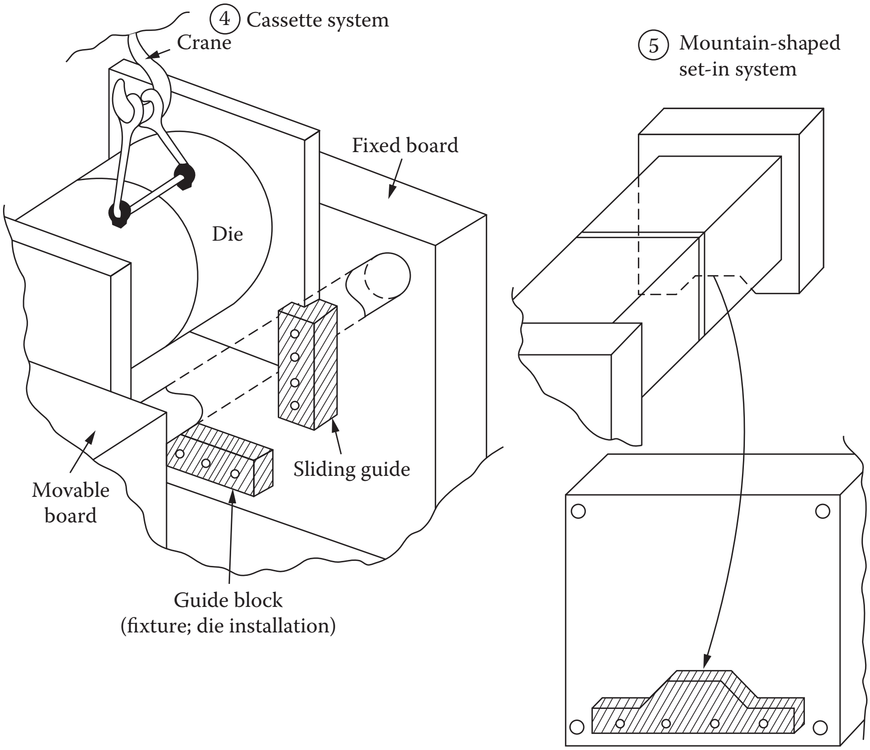


FIGURE 11.6
Setting-in systems for quick fastening (Technique 3): (4) cassette system with sliding guide block; (5) die-installation device with mountain-shaped guide.

Technique 5: Use Parallel Operations

The large punch press or the large molding machine will have many attachment positions on its left and right sides as well as on its front and back sides. The setup actions for such a machine will take one worker a long time. However, if parallel operations by two persons were applied to such a machine, wasteful movements could be eliminated and the setup time reduced. Even though the total number of labor hours for the setup was not changed, the effective operating hours of the machine could be increased. If a setup time of one hour were reduced to three minutes, the second worker would be needed for this process for only three minutes. Therefore, specialists in setup actions are trained on the punch press, and they cooperate with the machine operators.

Technique 6: Use a Mechanical Setup System

To attach the die, oil pressure or air pressure could be used for fastening at several positions at a time by the one-touch method. Also, the die heights of a punch press could be adjusted by an electrically operated mechanism. However, although such mechanisms are very convenient, an expensive investment in them would be "putting the cart before the horse."

Although Toyota has reduced the setup time to less than ten minutes, that shortened time is the internal setup time. The external setup still requires half an hour or one hour even at Toyota. Without this time span, the die for the next lot cannot be changed. As a result, the lot size or the number of setups per day at Toyota is essentially constrained by the time span of external setup.

In conclusion, for American and European companies, as well as companies of any other country, application of the Toyota Production System might pose some difficulties, such as labor union or geographical problems. However, the approaches to reducing the setup time described here can definitely be applied in any company and will reduce in-process inventory and also shorten the production lead time, although not as greatly as they would if accompanied by the kanban system. Reducing the setup times of many machines would be one of the easiest ways to introduce the Toyota Production System.

12

5S—Foundation for Improvements

§ 1 5S IS TO REMOVE ORGANIZATIONAL SLACK

In a plant, various opportunities exist that are often overlooked and left untouched in spite of their potential to make profits. These include, for instance, limiting the production of defects, the margin of operation efficiency (man-hour), excess inventories, and missed delivery deadlines. These overlooked opportunities, or slack, are referred to as *muda* in Japanese. Muda is essentially the waste of manpower, outputs, money, space, time, information, etc.

American organization theory recognized this as *organizational slack*, which was first described by R.M. Cyert and J.G. March (1963). In prosperous times, such slack is usually left as it is. But, during recessions, when companies are struggling, emphasis is immediately placed on trying to improve organizational slack and profits. However, the Japanese feel that the cut into the organizational slack must be constantly executed whether in prosperous or adverse times. The continuous implementation of smaller improvement activities is the principle behind "kaizen," an activity employed by many Japanese companies.

Kaizen, or "5S," is a method used to diminish the slack hidden in plants. 5S represents the Japanese words *Seiri, Seiton, Seison, Seiketsu*, and *Shitsuke*, which collectively translate to a cleanup activity at the workplace.

Over time, various kinds of dirt can accumulate in the plants and offices within a company. *Dirt* in a plant includes unnecessary work-in-process (WIP) inventories; defective inventories; unnecessary jigs, tools, and measures; inferior oil; and unneeded carts, equipment, tables, and so on. In an office, the unnecessary documents, reports, and stationery are *dirt* as well. 5S is the process of washing out all this dirt in order to be able to use the necessary things at the necessary time in the necessary quantity. By implementing 5S, the levels of quality, lead time, and cost reduction can be improved. These are the three main goals of production management. Mr. Hiroyuki Hirano believes that by promoting 5S, a plant can supply the products which customers want, in good quality, at a low cost, quickly, and safely, and thus increase company profits.

To achieve the aforementioned goals, the following muda, or slack, must be diminished:

1. ***Excessive setup time***. It is time consuming to look for dies, jigs, or tools needed to perform setup for the next operation. Setup time can be reduced or eliminated by neatly arranging in advance the necessary materials for a particular setup operation.
2. ***Defective materials/products***. Defects will become apparent in a clean plant. "Point photography," a concept that stimulates feelings of pride and shame in workers, is used to motivate workers to reduce defects. (Point photography will be discussed in more detail at the conclusion of this chapter.)
3. ***Cluttered work areas***. Cleanliness and neatness at the workplace increase the efficiency of operations. Conveying products becomes easier after eliminating unnecessary materials on the floor. A clean workplace raises worker morale, thereby increasing the attendance rate. In addition, since a clean facility reduces problems, the available operating time in a plant will also increase.
4. ***Missed delivery times***. To deliver products just-in-time, the inputs for making products, such as manpower, materials, and facilities, must flow smoothly. Since the lack of necessary units will be more visible in a clean plant, orders to replenish necessary supplies will become more efficient and less time will be wasted waiting for materials.
5. ***Unsafe conditions***. Improperly stacked loads, oil on the floor, etc., can cause injuries to workers and perhaps damage inventory, which will increase costs and delay delivery of products.

The 5S movement has several other merits to it. For example, it cultivates good human relationships in a firm and raises morale. A company, whose plants are clean and neat, will win the credibility of customers, suppliers, visitors, and applicants.

The components of 5S are defined as follows:

Seiri: **to clearly separate necessary things from unnecessary ones and abandon the latter**. As a means to practice Seiri, red rectangular labels (described later) are used so that only necessary things will remain within the plant.

Seiton: **to neatly arrange and identify things for ease of use**. The Japanese word *Seiton* literally translated means laying things out in an attractive manner. In the 5S context, it means arranging materials so that everyone is able to find them quickly. To realize this step, indicator plates are used to specify the name of each item and the address of its storage.

Seiso: **to always clean up; to maintain tidiness and cleanliness**. This is a basic cleanup process in which an area is swept with a broom and then wiped with a floor cloth. Since floors as well as windows and walls have to be cleaned, Seiso here is equivalent to the large-scale cleanup activity carried out at the end of each year in Japanese households. Although such company-wide, large-scale cleanups are conducted several times a year, it is important for each workplace to be cleaned daily. Such activities tend to reduce machine malfunctions caused by dirty oil, dust, and rubbish. For example, if a worker complains that a machine is malfunctioning, it does not necessarily mean that the machine needs a tune-up. In fact, a program of workstation housekeeping may be all that is necessary.

Seiketsu: **to constantly maintain the 3S mentioned above, Seiri, Seiton, and Seiso**. Keeping a clean workplace without rubbish or oil leakage is the activity of Seiketsu.

Shitsuke: **to have workers make a habit of always conforming to rules**. According to Dr. Eizaburo Nishibori (1985), Shitsuke is the most important discipline of the 5S. Therefore, a person who trains others must first exhibit superior behaviors.

Managers should not expect their subordinates to simply follow their designations; they should *inspire* their subordinates and expect their success rather than giving flat criticisms. Managers should listen to their subordinates' ideas and express encouragement by saying "your idea is interesting." Even when a fault is obvious, managers should teach subordinates to recognize the fault themselves and either make a suggestion or tolerate the failure. Managers who criticize subordinates without first giving them the opportunity to challenge themselves cannot cultivate proficient subordinates.

For 5S to be effective, workers must make a habit of placing things near at hand for easy access. Having only the knowledge of 5S is not enough; workers must also practice 5S over and over. It should become a spontaneous, natural act of their own volition rather than something they are forced to do.

Below are guidelines for practicing 5S. For these, the author is indebted to the splendid ideas of Mr. Hiroyuki Hirano (1990), Mr. Tomoo Sugiyama (1985), and others.

§ 2 VISUAL CONTROL

For improvement activities to take place, every employee—from top management to terminal worker—must have and share a strong consciousness to eliminate the hidden wastes, abnormalities, and various other problems within the plant. These problems must be visible to every employee; hence, Seiri and Seiton are the first two steps toward improvement (see Figure 12.1).

To recognize wasted items, materials are separated into *necessary* and *unnecessary* stacks. Then, "visual Seiri" is attained by using red labels; "visual Seiton" is attained using indicator plates.

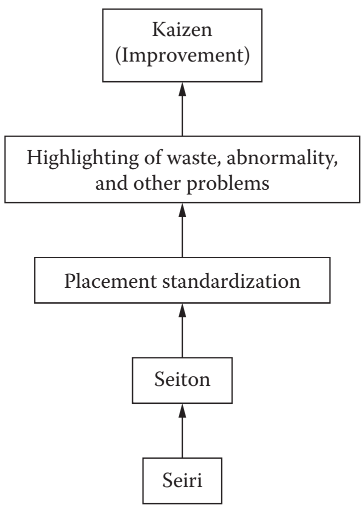


FIGURE 12.1
Seiri and Seiton: first steps of kaizen.

Visual Seiri

In a plant, dirt will gather over time and allow wastes to build up. At Toyota, red labels are used to seal the wastes and expose them for what they are. They are then completely thrown away.

The red label technique consists of the following six steps, which must be conducted about twice a year:

Step 1. Establishment of a red label project. There are two kinds of red label strategies: *the red label at each workplace* and *the company-wide red label*. The former should be done every day, while the latter should be done only once or twice a year. The company-wide red label project is similar to the large-scale cleanups conducted in Japanese households at year-end. For this company-wide red-labeling project, top management's enthusiasm is indispensable. The president should be the chair of the red label project.

Step 2. Determination of objects to be sealed. Items that need to be controlled and sealed by red labels are inventories, machinery, and space. Inventories include materials, WIP, parts, half-finished products, and finished products. Machinery includes machines, facilities, carts, pallets, jigs, tools, cutting instruments, tables, chairs, dies, vehicles, and equipment. Space represents the floors, passages, shelves, and storages.

Step 3. Determination of labeling criteria. Although the instructions are to seal the unnecessary items with red labels, it is sometimes difficult to determine which items are unnecessary. Therefore, specific criterion must be developed to draw a sharp line between the necessary items and the unnecessary ones. In general, parts, materials, machines, and so on, that will not be used during the upcoming month will be regarded as redundant. As Seiri proceeds, this time criteria may be reduced to the upcoming week.

Step 4. Preparation of labels. Figure 12.2 shows labels containing the date, name of the checker, item classification, item name, quantity, department name, actions, and reasons to be sealed (e.g., defective units, noncritical units, or unnecessary units). Even if it is difficult to judge whether or not to seal an item, the red label should be applied. All red-labeled items will be grouped and evaluated one more time before being disposed.

Model	SZ-250P
Product name	door
Lot size	40
Quantity	1 pallet
Process	door welding
	Sep. 2/1990
Reasons	Dent

(The actual size is 5" × 5".)

Classification	1. Facilities 2. Jigs and tools 3. Measures 4. Materials 5. Parts	6. Works in-process 7. Half-finished products 8. Completed products	9. Sub-materials 10. Clerical supplies 11. Documents
Item name			
Number			
Quantity			
Reasons	unnecessary, defective		
Department			
Date			

FIGURE 12.2
Standard red labels.

Step 5. Labeling. A member of the management staff should do the actual labeling. They are able to assess conditions more objectively than would a person directly in charge of the workplace.

Step 6. Evaluation of sealed items and recommended actions. Sealed inventories are classified into four groups: defects, dead stock, staying items, and leftover materials. At this stage, the defects and dead stock (i.e., old models no longer used) should be thrown out, whereas staying items (excess inventories) should be transferred to the red label storage. The leftover materials (scraps) should be examined for usability. Unusable leftover material is discarded, while the usable parts are placed in red label storage.

After finishing the sealing process, the results should be summarized in a *list of unnecessary inventories* and a *list of unnecessary facilities* as shown in Figure 12.3. Each list should conclude with a recommendation for action and/or counter-measure.

List of Unnecessary Inventories							
Department						Date ___________	
Item name	Code	Quantity	Unit cost	Cost	Disposal	Provision	References
Total amount of unnecessary inventories					Disposal value Others		
Countermeasures and improvement points							

List of Unnecessary Facilities									
Department								Date ______________	
Name of facility	Code	Quantity	Unit cost	Purchase cost	Purchase date	Accumulated depreciation cost	Book value	Located place	References
Total amount of unnecessary facilities									
Countermeasures and improvement points									

FIGURE 12.3
Lists of unnecessary inventories and facilities.

Indicator Plate for Visual Seiton

After the red labeling elimination process, only necessary items are left. The next step is to distinctly show where (position), what (item), and how many (quantity) materials exist so they can be easily recognized.

Visual Seiton allows workers to easily identify and retrieve tools and materials and then readily return them to a location near the point of use. Indicator plates are used to facilitate ease of location and retrieval of needed materials. The following steps are taken before indicator plates are attached to materials:

1. Decide item placement.
2. Prepare containers.

3. Indicate the position for each item.
4. Indicate the item code and its quantity.
5. Make Seiton a habit.

Step 1—Decide Item Placement

The principle behind determining a location for each item is to define the items that are used frequently and then place them around the workers who use them. Other less frequently used items are placed farther away. Additionally, items should be located at a height between a worker's shoulders and waste. This method decreases the amount of time and energy spent walking to and from storage areas.

Step 2—Prepare the Container

After deciding on the space, containers such as boxes, cabinets, shelves, pallets, etc., must be prepared. However, purchasing new containers should be absolutely avoided since the ultimate objective is to reduce space and minimize the size and quantity of inventories.

Step 3—Indicate the Position for Each Item

Indicator plates containing *place codes* are created and hung from the ceiling. The place code is the address of the item's location. It is made up of the *place address* and the *spot address* (see Figure 12.4). In addition to these indicator plates, more specific *spot plates* are placed on each shelf.

Step 4—Indicate the Item Code and Its Quantity

Item codes and quantities are specified on the item itself via an *item code tag* and on the shelf the item occupies via an *item code plate*. The application of these item code plates is similar to the system for assigning parking spaces in a parking lot. In this example, each car's number plate corresponds to the item code tag. Item code plates correspond to those placed at the head of each parking spot showing the owner's name and plate number (see Figure 12.5).

As for the quantity indication, the maximum (lot size) and minimum (reorder point) quantities of inventories are specified. Instead of using written numbers for these quantities, it is better to express the desired

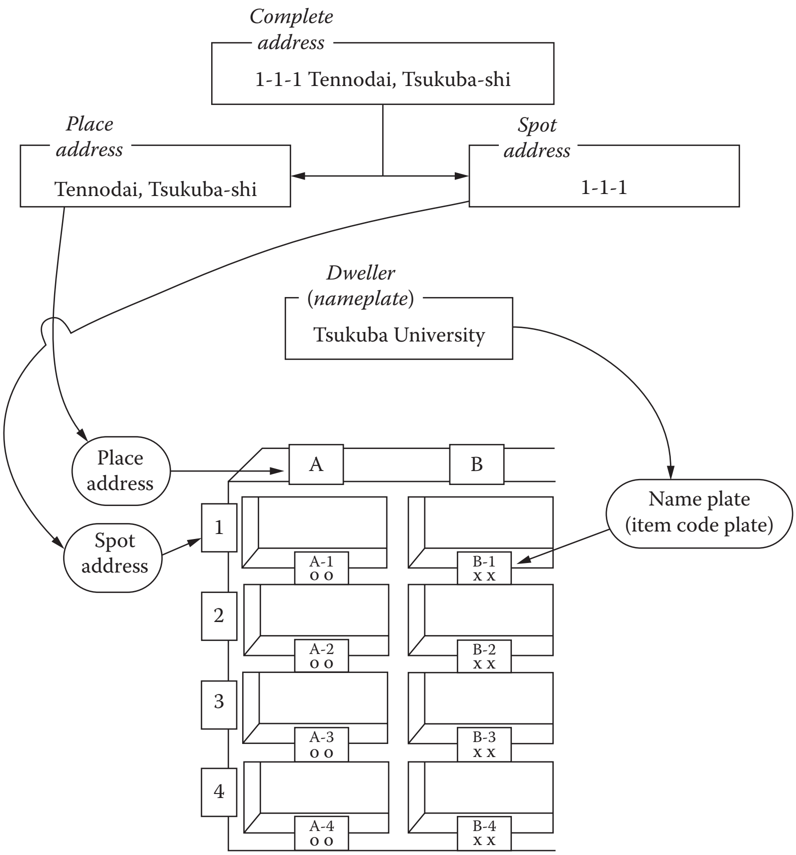


FIGURE 12.4
Place plate, spot plate, and item code plate.

quantity visually by drawing a conspicuous colored line at the proper position. This will enable the operator to obtain the maximum and minimum quantity level at a glance without having to read every written number (see Figure 12.6).

Step 5—Make Seiton a Habit

To continuously maintain order in a plant, Seiri and Seiton must be performed adequately. These actions include visual separation of necessary and unnecessary materials, organization of frequently used stock at nearby places, and the use of place code plates, item code plates, and quantity indicator lines.

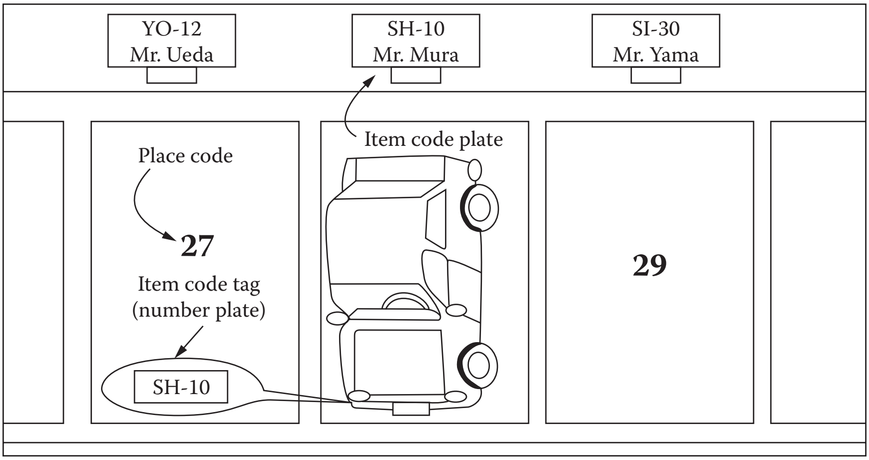


FIGURE 12.5
Item code plate and item code tag in a parking lot.

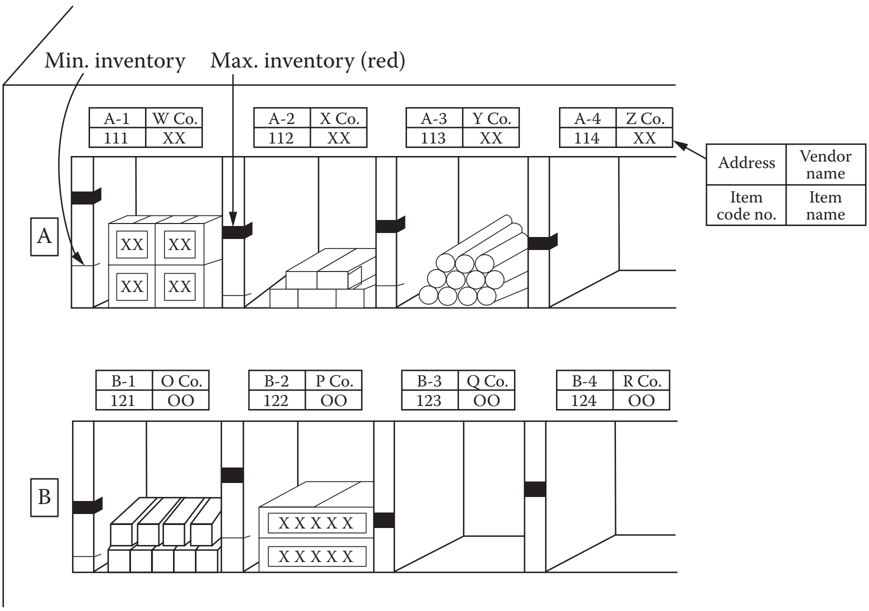


FIGURE 12.6
Indication of maximum and minimum quantities of inventories.

§ 3 PRACTICAL RULES FOR SEITON

Seiton of WIP

Seiri and Seiton are typically applied to WIP. The Toyota Production System specifically emphasizes the importance of inventory reduction. Improvement activities will progress easily only if the existence of wastes, abnormalities, or problems is perceived by everyone in the entire plant. These problems include excessive WIP inventories, defective units, and inventories whose completion is held up by machine troubles at subsequent assembly stations.

So that any operator can recognize the occurrence of abnormalities, item placement is standardized by using indicator plates. For example, a quick glance will enable anyone to easily notice whether or not boxes of a certain item are where they should be, or if they have exceeded the limit line of maximum quantity.

Rules of Seiton for WIP will be discussed below.

Rule 1: First-In, First-Out

In Seiton, it is very important to correctly load and set up the WIP. The principle of First-In, First-Out (FIFO) must be observed so that things put in first can be taken out and used first. FIFO is preferred over another rule of loading, Last-In First-Out (LIFO), where new parts are piled over old ones. Under LIFO, only the new parts are used and the old ones remain at the bottom, unused, which can create a potential quality control problem.

When loading stock via a forklift, the position of each pallet will be determined by the direction of the fork. Therefore, if pallets are placed in the direction as shown in Figure 12.7a, they could not be withdrawn according to FIFO. A space of passage for carriers must be made as in Figure 12.7b. The storage racks should be broad in width and short in depth like a chest of drawers, or have many entrances and short-depth.

Rule 2: Setup for Easy Handling

It is said that 30 to 40 percent of processing costs and 80 to 90 percent of processing time is spent on material handling. Therefore, improvement in material handling is very important for efficient plant operation. Using

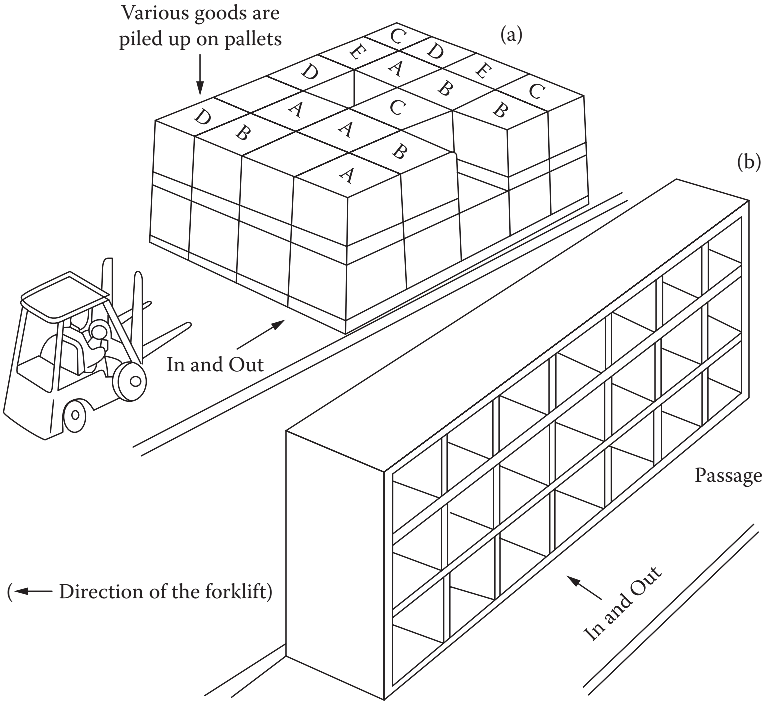


FIGURE 12.7
"First-In, First-Out" requires broad width and short depth.

a *material handling index of liveliness*, as shown in Figure 12.8, can help determine the best method of conveyance, i.e., pallet, cart, fork lift, etc.

The index of liveliness is calculated by classifying the number of required tasks into five levels of activity. Then, the sum of the levels is divided by the number of steps in the process (see Figure 12.9).

With this index, material handling activity can be analyzed as shown in Figure 12.9. If the averaged index of liveliness is less than 0.5, containers, pallets, and carts should be prepared instead of putting items directly on the floor. If the average index is less than 1.3, many more uses of the pallets, carts, and forklifts are recommended.

Rule 3: Regard Stock Space as Part of Manufacturing Line

Since a tremendous variety of parts, materials, jigs, and tools exists, it is necessary to position them for easy access by their users. If the user is working in a job-shop situation, parts should be stored based on similarity

Classification	Index of liveliness	Number of required tasks	Variety of required tasks				Conditions
			Group	Raise	Lift up	Bring	
In bulk	0	4	○	○	○	○	Left in bulk directly on the floor or tables
Unified in a box or batch	1	3	--	○	○	○	Placed in a container or grouped in a bundle
In box with bolsters	2	2	--	--	○	○	Raised by pallets or skids
On a carriage	3	1	--	--	--	○	Set on carriages or something with castors
On the move	4	0	--	--	--	--	Moving by conveyor, chute, or carriages

FIGURE 12.8
Material-handling index of liveliness.

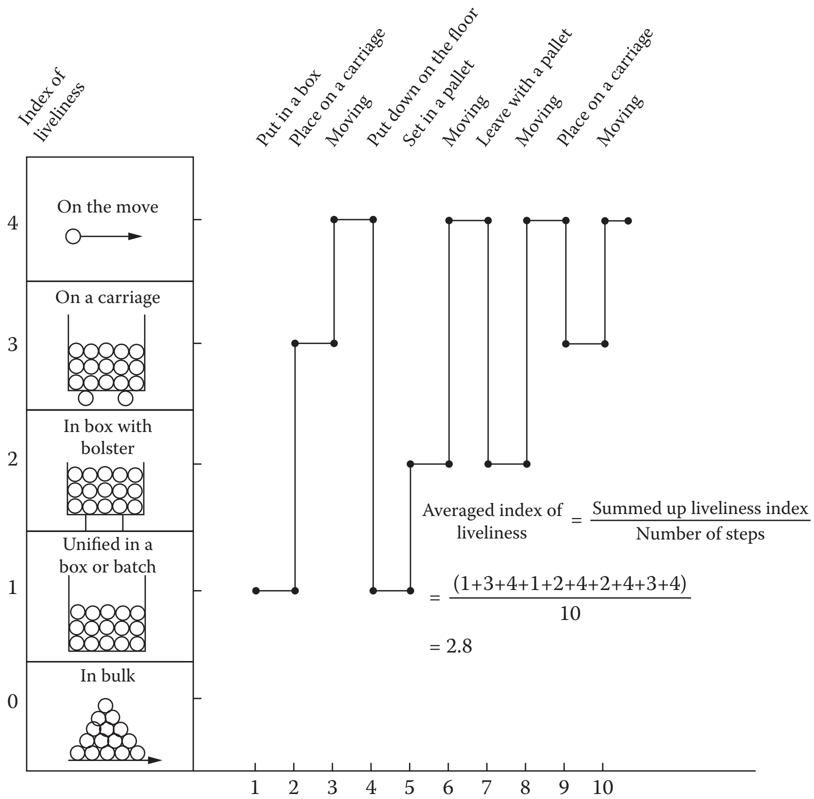


FIGURE 12.9
Averaged material-handling index of liveliness.

of function. If the user is mass-producing a product, parts should be arranged and stored according to the production line.

In either method, however, it is important to clearly separate defective items from good ones and make them strikingly different. Hence, storage for defects should be red-colored, located outside the product lines, and placed piece-by-piece.

Seiton of Jigs and Tools

Perhaps the most used items in an automobile manufacturing plant are tools and jigs, and there are many varieties of each. As already discussed, it is important to have these items neatly arranged in close proximity to the worker, but it is just as important to devise a way for the worker to return these materials with ease after each use. Following are some considerations for accomplishing this goal:

Point 1: Can jigs and tools be eliminated? Consider whether a function can be performed effectively without jigs or tools. For instance, suppose a screw is currently tightened using a wrench. If the screw can be modified into a switch shape, the function can be performed by hand instead.

Point 2: Can the variety of jigs and tools be decreased? Consider whether the variety of fastening operations can be consolidated into a smaller variety by standardizing at the design stage.

Point 3: Are tools positioned ergonomically? Wasted motion and the possibility of injury to the worker can be avoided by placing frequently used items between the worker's waist and shoulders.

Point 4: Can the worker easily identify storage places for tools? Tracing the outline of a tool or jig on the place where it is to be stored allows the worker to easily recognize where to return the item. This is one of three approaches toward satisfying Seiton as it relates to storing tools (see Figures 12.10 and 12.11).

Another method, *blindfold returns*, where items are placed into sacks rather than hung on a peg board in a specified location, allows the worker to release the tool in an approximate position without having to follow it with his eyes.

The third alternative is perhaps the most ideal method because it allows workers to immediately and unconsciously return tools. This is the method of suspending tools on cables hung from the ceiling.

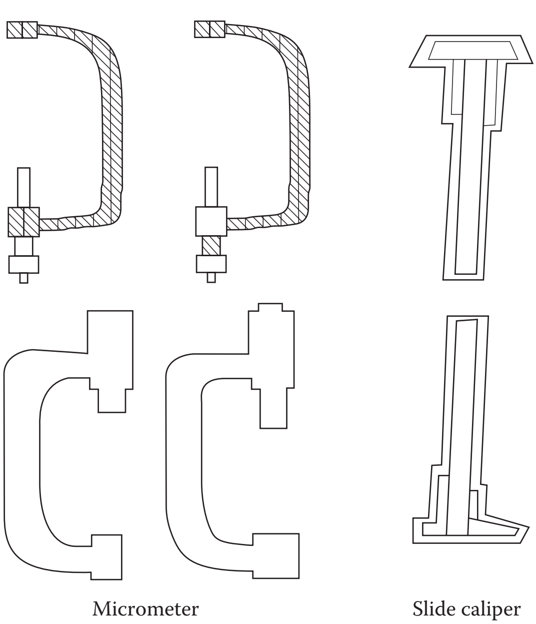


FIGURE 12.10
Tracing control.

Seiton of the Cutting Instruments, Measures, and Oil

Storage of cutting instruments such as drills, taps, grinders, etc., should be determined based on how frequently the instruments are used. If the instruments are used at many machines for mass production, the product line system (previously discussed) would be most suitable. On the other hand, if used in a job shop situation, the instruments should be stored according to their function.

Since these instruments have sharp edges, careful attention to how they are stored is important. Adequate space between blades should be provided in order to protect the blades and for ease of maintenance (oiling). Figure 12.12 illustrates how and on what type of surface cutting instruments should be stored.

Other sensitive tools such as calipers, gauges, micrometers, straight rulers, etc., require special attention as well. To keep these measuring tools accurate, it is imperative to protect them from dust, dirt, and vibration. Some will require oiling to protect from rust. The straight ruler should be hung up in a perpendicular position to avoid warping.

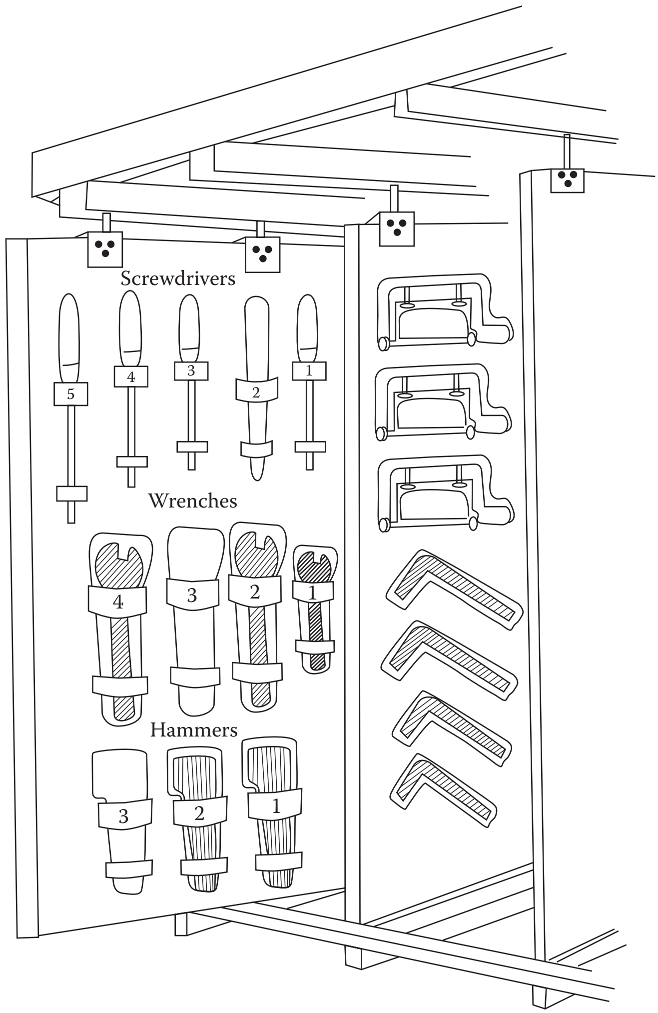


FIGURE 12.11
Blindfold return and a drawing cabinet exclusively for tools.

Many types and grades of oil are used in manufacturing plants. Often the oil arrives in large containers and is then transferred to smaller, more manageable containers. To avoid mix-up, a color coding system should be implemented. Oil drums and their respective oil feeders should be painted or marked with the same color. Also, the filling station should be marked with the same color as the drum and feeder.

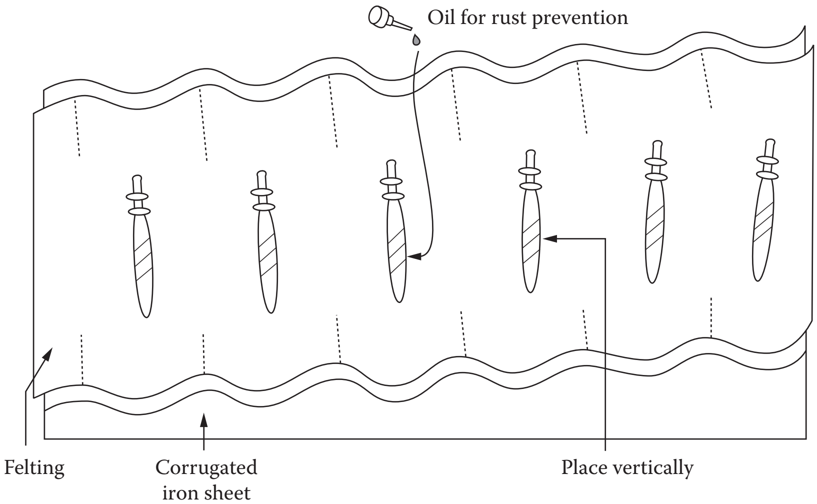


FIGURE 12.12
Maintenance of cutting instruments.

Visual Controls for Limit Standards

Visual indicators are extremely effective when used for control limits because they are easily recognized by everyone with just a glance. Some examples are described below.

- A meter-zone indication is used to separate a danger zone from a normal zone. The indicator can be a color or a line. The zone method is also used to indicate the minimum allowable stock quantity of WIP.
- Fit marks are lines that are drawn on, for example, from the head of a bolt to a nut at the properly fastened position. When the respective parts of the line on the bolt and the nut do not coincide with each other, then the bolt is loose. This idea has wide applications.
- To maintain a certain level or condition, a needle can be used to mark each control limit on every measure. When the needle crosses over the limit point, abnormal conditions will become apparent. A mark on the oil-level window of an oil stove is one such example.
- Spot marks and stop lines are used for marking the position of an item and for depicting the position to stop. For example, to adjust the center of a die, a center pin or a spot mark indicates the die's accurate position on the pressing table.

- Separation lines drawn with white paint or vinyl tape divide passageways and workplace areas thus maintaining the high level of safety within a plant. Similar lines should also be used to indicate storage locations of carts, products in process, jigs, instruments, and cleanup tools.

§ 4 SEISO, SEIKETSU, SHITSUKE

The latter three terms in 5S are closely interrelated. "Seiso," to continually maintain tidiness within the plant, depends on "Seiketsu," which is to standardize cleanup activities so that these actions are specific and easy to perform. "Shitsuke" is the method used to motivate workers to continually perform and participate in Seiso and Seiketsu activities.

Daily preventative maintenance activities and general cleanup activities can reveal the following conditions on the shop floors:

- Rubbish
- Water and oil leaks
- Tire marks
- Dust scattered by cutting materials

Once revealed, it is necessary to investigate the causes and origination of the dirt and then implement a system of future prevention.

Countermeasures against dirtiness must be taken at the source. For example, if tire tracks from a forklift are found on the floor, it can be deduced that abrupt starts and sudden stops are the cause. A placard stating, "Sudden starts and stops generate dirt," may help to prevent future tire track conditions. Forklifts can also be equipped with a tire-washing brush or a mop for cleaning the passages.

Perhaps the largest source of dirt in workplaces comes from cutting instruments (e.g., dust, oil, cutting solution). As seen in Figure 12.13, most covers installed around a grinder for collecting dust are inappropriate. The necessary improvement can be seen by testing the grinder with a piece of chalk. When ground, the chalk will show the area that should be covered to collect dust particles. In addition to installing a cover that will collect the dust at the point of grinding, dust can also be controlled by covering the legs of the machines. By doing so, cleanup work under machines and

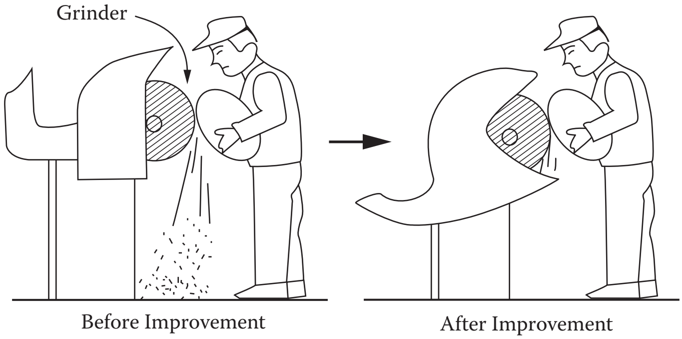


FIGURE 12.13
Use of dust collecting covers.

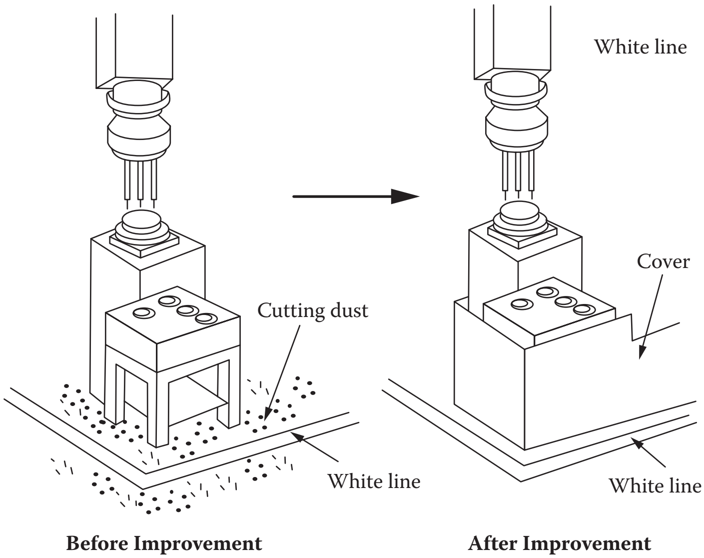


FIGURE 12.14
Cover around legs of machines and tables for rapid cleanup.

tables should become easier and faster—perhaps by as much as 50 percent. Note that covers must be designed for easy removal when performing machine maintenance activities (see Figure 12.14).

Shitsuke, motivating workers to perform maintenance and continuous improvement activities, is considered the most difficult component of 5S. Japanese workers are expected to exercise *self-control*—instead of being controlled by management—for this activity.

Initially the Japanese followed the Western belief that control could be achieved by setting a goal for the worker and then rewarding, or "giving a carrot," if the goal was met. If the goal was not met, discipline, or "a stick," would be offered. However, Japanese workers did not respond as expected. Instead, they were offended by the strict orders to comply.

Subsequently, the notion of *self-control* was implemented. Management's role here was just to inform their subordinates of the purposes of their jobs, and entrust them with all the details of the job. The result was subordinates who not only produced things, but who also had a sense of responsibility for the quality of the products they made.

It was found that the emotions of pride and shame influenced Japanese workers more than the "carrot and stick" incentive system. The worker's conscience was the motivator. Workers are evaluated based upon the comparison between their own present and past performances and between theirs and other workers' performances. In other words, the desire to improve oneself and a sense of rivalry were used to motivate people to control themselves. A suggestion system was also implemented as a source of limitless power for improvement activities.

The Japanese administrative system is very collective in that workers have a feeling that their superior is one that works together with the company. Although they are merely told of the purpose of their work, each subordinate is conscious of the necessity to perform self-control to become part of the team. Under such a condition, challenging and competitive spirits serve as strong motivators for improvement.

Motivation to improve, or Shitsuke, is the essence of the Japanese management system.

§ 5 PROMOTION OF 5S SYSTEM

Promoting 5S depends on top management's decisions. When implementing any continuous improvement process such as 5S there will be those in management who have doubts about whether the process will succeed. They will say, "How much indeed will the productivity increase?" or "How much will 5S contribute to the actual profits?"

Before implementing a process like 5S, people's ways of thinking and their attitudes toward work must first be changed. All members of the company must have a sufficient understanding of its real meaning and purpose, and they must integrate their understandings through company-wide or workplace-wide seminars. It is also useful to hang some banners with slogans such as: "Clean workplaces are created by using the power of everyone," or "There is no waste in a clean workplace," and so on.

Since 5S activities require long-term continuous efforts, it is necessary for the entire company to understand its purpose. Some members of management may think that they have nothing to do with Seiri and Seiton, and so on, regarding them as matters of the floor-level workplace. This is the reason the existing organizational structure in a company should be utilized in promoting 5S throughout the entire plant.

Success or failure of 5S depends on top management's wishes and whether or not the initiative was taken. Establishment of a 5S project should be chaired by the top management, and a leader of each workplace must be the first to practice it and exhibit a good example. If management and workplace leaders show a strong commitment to 5S, their subordinates will too and 5S will be successful.

Point Photography

In conclusion, *point photographing*, a method that is considered to be a strong motivational tool for 5S, will be introduced.

Point photography is the practice of taking pictures of the same position of the workplace from the same direction by the same camera before and after the application of 5S. These photographs are then shown to workers to be compared. Point photography works because of the feelings of pride or shame evoked when workers see the comparisons. Special effort should be made to photograph areas that workers especially do not wish to be seen by others, such as facilities with oil leaks, scattered cutting dust, disorganized tools, and any other unsafe spots.

A *point photographing chart*, depicted in Figure 12.15, is used to display the pictures. It contains a space for the date the picture was taken, a column for evaluation by safety patrols or others, and a space for advice from a superior or humorous comments from other colleagues.

Each time an improvement is made, a picture should be taken and posted next to the last photo taken to show a chronological series of improvements. If the date of point photographing is known in advance and can be clearly noted on the chart, it becomes a goal and will help raise workers' desire to show improvements by that date. These charts are also used by superiors for evaluation purposes.

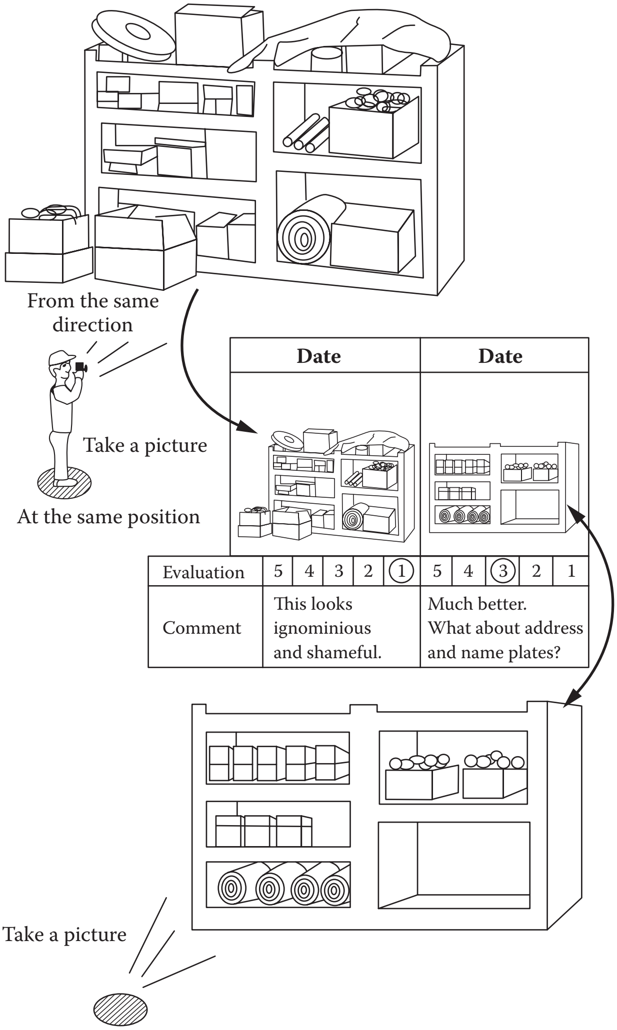


FIGURE 12.15
Point photography method.

Point photography is a remarkable stimulant to workers and enables management to effectively continue with improvement activities. Through point photography, workers can visually see the pride or shame of their workmanship. Realization that improvement is needed becomes a spontaneous reaction to an embarrassing photograph. Conversely, if the point photography reveals that the rules of 5S have been followed, the worker has set a good example and is looked up to by his colleagues.

13

Autonomous Defect Control Ensures Product Quality

§ 1 DEVELOPMENT OF QUALITY MANAGEMENT ACTIVITIES

In Japan, quality control (QC) or quality assurance (QA) is defined as the development, design, manufacture, and service of products that will satisfy the consumer's needs at the lowest possible cost. As the definition implies, the customer's satisfaction with product quality is an end in itself at Toyota. At the same time, however, product quality is an indispensable part of the Toyota Production System, since without quality control the continuous flow of production (synchronization) would be impossible.

The evolution of the Japanese approach to quality control and its application to specific needs and problems with the Toyota Production System will be examined in this chapter. As Figure 13.1 shows, quality control began with independent inspectors and statistical sampling methods but soon moved to a "self-inspection of all units" method, which is based on autonomous control of defects within the manufacturing process itself. Quality control has now become a company-wide concern that extends outward from manufacturing to Toyota's functional management units.

Until 1949, quality control activities in Japan were largely a matter of rigorous inspections carried out by specialized inspectors: an approach that has been all but abandoned in present-day quality control programs. Today in Japan, less than 5 percent of factory employees are inspectors, and in the top companies fewer than 1 percent. By contrast, in America and Europe, where quality control activities are seldom entrusted to workers on the line, nearly 10 percent of all factory employees are inspectors.

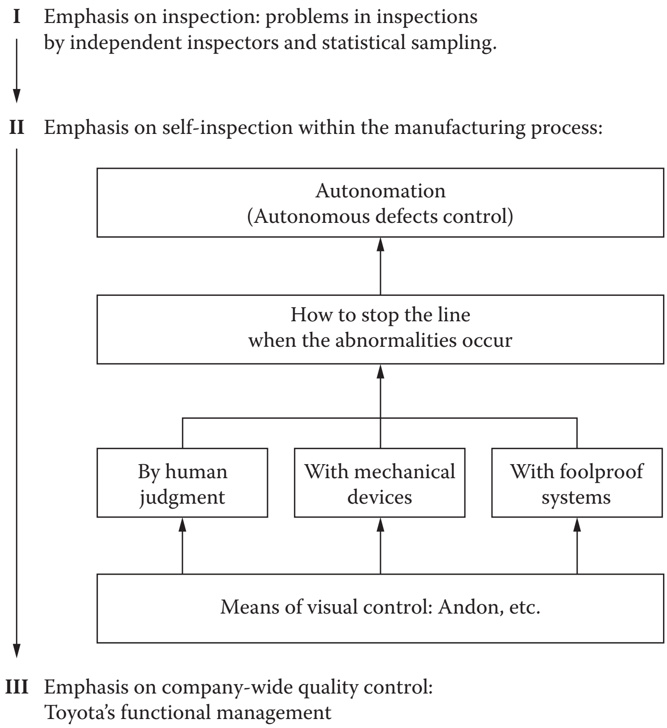


FIGURE 13.1
Evolution of quality control activities at Toyota.

In Japan, inspections by specialized inspectors have been minimized for a number of reasons: inspectors whose activities stand outside the manufacturing process perform operations with no value added and thus add to production costs without increasing productivity. Also, feedback from the inspectors to the manufacturing process usually takes so long that defective parts or products continue to be produced for some time after a problem is discovered.

Under the present system, the manufacturer or manufacturing process is itself responsible for quality control; those who most directly produce defective parts are immediately aware of problems and are charged with the responsibility for correcting them. As a result, few inspection procedures are assigned to specialized inspectors; usually the final inspections are made from the point of view of the consumer or management and are not inspections for defects that would affect the flow of production.

§ 2 STATISTICAL QUALITY CONTROL

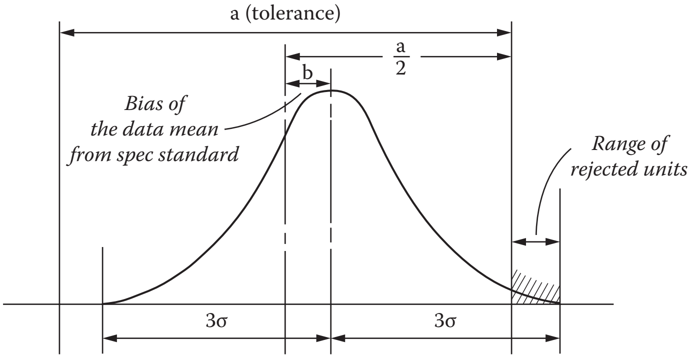
Statistical quality control (SQC) originated in America in the 1930s as an industrial application of the control chart devised by Dr. W. A. Shewhart. It was introduced to Japanese industry after World War II, largely as the result of a lecture tour by Dr. W. E. Deming in 1950.

Although statistical quality control is still an important technique in Japanese QC systems, it too has certain drawbacks:

- In SQC, the acceptable quality level (AQL), which determines products that are passed but are of the minimum acceptable quality, is fixed at 0.5 percent or 1.0 percent. Either level, however, is unsatisfactory from the point of view of companies that aim for very high producer quality (e.g., a defect rate of one in a million). At Toyota, for example, the goal of quality control is to obtain 100 percent good units or a defect rate of zero. The reason for this is quite simple: even though Toyota may produce and sell millions of automobiles, an individual customer buys only one. If his car has defects, he will think—and tell his friends—that Toyotas are "pieces of junk."
- Under the Toyota Production System, excess inventory is a type of waste and thus is not permitted. Furthermore, just-in-time (JIT) production, or the ability to meet demand changes with a minimum of lead time, also makes it necessary to minimize inventory. If defective workpieces occur at any stage in the process, the flow of production will be interrupted and the entire line will stop.

For both reasons, then, Toyota is unable to rely on statistical sampling alone and has been forced instead to devise inexpensive means of conducting inspections for all units ("total inspection") to ensure zero defects.

Statistical sampling is still practiced at certain departments where lot production takes place. At a high-speed automatic punch press, for example, where lots of 50 or 100 units are kept in a chute, only the first and last units in the chute are inspected. If both units are good, *all* units in the chute are considered good. If the last unit is defective, however, a search will be made for the first defective unit in the chute, all defective units in the chute will be removed, and remedial action taken. So that no lot will



Process capability index (Cp) = $\frac{a}{6\sigma}$

Degree of bias (β) = $\frac{b}{a/2}$

Condition for not producing the rejectable units:

$b + 3\sigma < a/2$

or

$Cp(1 - \beta) > 1.$

$Cp \geq 1.33$ or $\alpha \geq \beta\ \sigma$ at Toyota group

FIGURE 13.2
Process capability for quality and the bias.

escape inspection, the punch press is set to stop automatically at the end of each lot.

Use of statistical sampling is in effect a total inspection since it is used only when an operation has been fully stabilized through careful maintenance of equipment and tools and sporadic defects do not occur. In such cases, the distribution of the product's data variation (6 × the standard deviation) will be relatively small compared to the designed tolerance, and the bias of the data mean from the central value of the designed specification will also be small (Figure 13.2). Under such conditions, the sampling inspection plan will guarantee the quality of all units in the chute.

In effect, then, all unit inspection or its equivalent has been substituted for ordinary statistical sampling, just as inspections within the manufacturing process itself have been developed to replace inspections by independent inspectors. In both cases, more traditional methods of quality control have been replaced by self-inspection of all units in the interest of further reducing the number of defective units. This approach to quality control is called *jidoka* or *autonomation*.

Jidoka =
1. 自動化 = Automation
2. 自働化 = Autonomation

FIGURE 13.3
Two meanings of jidoka.

§ 3 AUTONOMATION

In Japanese, *jidoka* has two meanings and is written with two different ideograms (Figure 13.3). One ideogram means automation in the usual sense: to change from a manual process to a machine process. With this kind of automation, the machine operates by itself once the switch is thrown but has no feedback mechanism for detecting errors and no device for stopping the process if a malfunction occurs. Because this type of automation can lead to large numbers of defective parts in the event of a machine malfunction, it is considered unsatisfactory.

The second meaning of *jidoka* is *automatic control of defects*, a meaning coined by Toyota. To distinguish between the two meanings of jidoka, Toyota often refers to the second type of jidoka as "Ninben-no-aru" jidoka or, literally translated, *automation with a human mind*. Jidoka translates to autonomation in English. (Autonomation in a broad sense also means to devise mechanisms for making the machine stop automatically when it finishes each automated processing task. See Section 4 of Chapter 9, and Figure 9.1.)

Although autonomation often involves some type of automation, it is not limited to machine processes. It can be used in conjunction with manual operations as well. This is a different point from the Detroit technique called "Feedback Automation." In either case, it is predominantly a technique for detecting and correcting production defects and always incorporates a mechanism to detect abnormalities or defects, and a mechanism to stop the line or machine when abnormalities or defects occur.

In short, autonomation at Toyota always involves quality control since it makes it impossible for defective parts to pass unnoticed through the line. When a defect occurs, the line stops, forcing immediate attention to the problem, an investigation into its causes, and initiation of corrective action to prevent similar defects from occurring again. Autonomation

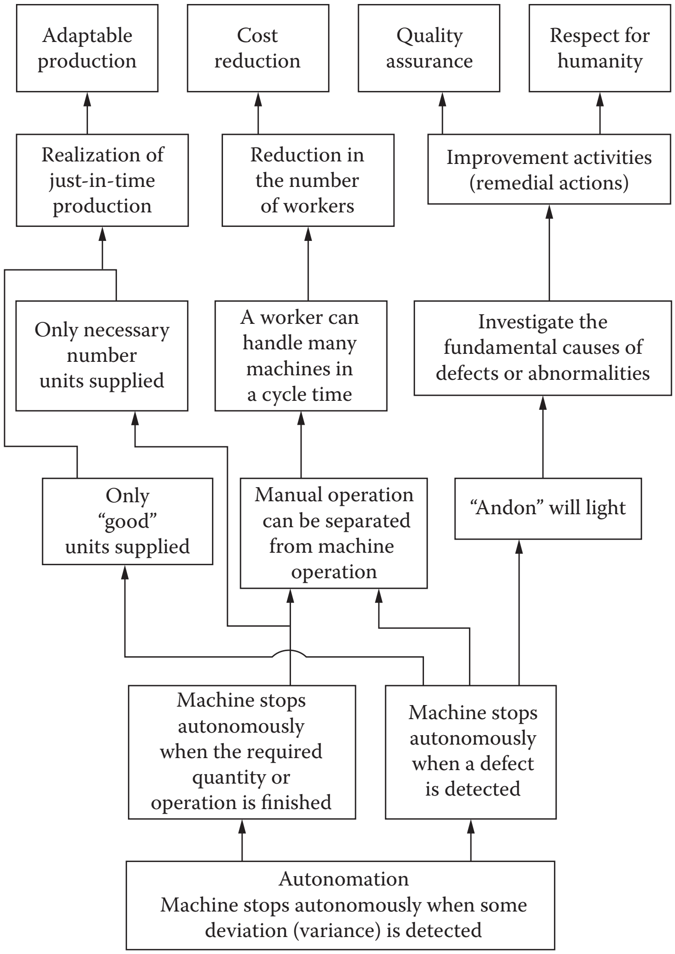


FIGURE 13.4
How autonomation attains its purposes.

also has other equally important components and effects: cost reduction, adaptable production, and increased respect for humanity (Figure 13.4).

Cost reduction through decreases in the workforce. With equipment designed to stop automatically when the required quantity has been produced or when a defect occurs, there is no need for the worker to oversee machine operations. As a result, manual operations can be separated from machine operations, and a worker who has finished his work at machine A can go on to operate machine B while machine A is still running. Autonomation thus plays an important role in refining the standard operating routine: the worker's ability to handle more than one machine at a time makes it possible to reduce the workforce and thus the cost of production.

Adaptability to changes in demand. Since all machines stop automatically when they have produced the required number of parts and produce only good parts, autonomation eliminates excess inventory and thus makes possible JIT production and ready adaptability to changes in demand.

Respect for humanity. Since quality control based on autonomation calls immediate attention to defects or problems in the production process, it stimulates improvement activities and thus increases respect for humanity.

§ 4 AUTONOMATION AND THE TOYOTA PRODUCTION SYSTEM

Having examined the purposes of autonomation, we next consider its application to the Toyota Production System; i.e., the specific types of devices used to stop the line when defects occur, the techniques employed to accustom the workers to autonomated production, and the means for monitoring production and correcting abnormalities when they occur.

Methods for Stopping the Line

In general, there are two ways to stop the line when abnormalities occur: by relying on human judgment and by means of automatic devices.

Each worker has the power and the responsibility to stop the line if all operations are not or cannot be performed in accordance with the standard operations routine. The causes are either a reduction in the number of workers (Shojinka), which results in a cycle time that is too short, or defective units produced at the preceding process, making it necessary for the worker at the next process to stop the line. If, for example, it takes a worker 80 seconds to complete his assigned operations and his cycle time is 70 seconds, he must stop the line for ten seconds at each cycle. Otherwise, he will be unable to finish his work and defects will occur. When the line stops, supervisors and engineers must investigate the problem and undertake improvement activities in order to reduce the actual operations time from 80 to 70 seconds. Such activities may include elimination of wasteful actions, shortening of walking distances, etc.

Defective units produced at the preceding process usually appear when reductions in intermediate inventory under the kanban system or reductions in the workforce, make it impossible to replace the defective units from inventory or repair them during waiting time. As a result, the line must stop when the defects appear, which calls attention to the problem and presents an opportunity for further improvement activities. Design defects, for example, or a continually omitted operation at the previous process may surface in this way (Figure 13.5).

With line stoppages due to defective units or revisions of the standard operations routine, the supervisor's responsibility is twofold. First, he must teach the workers to stop the line whenever defects occur so that only good units are delivered. Second, he must discover and correct the cause

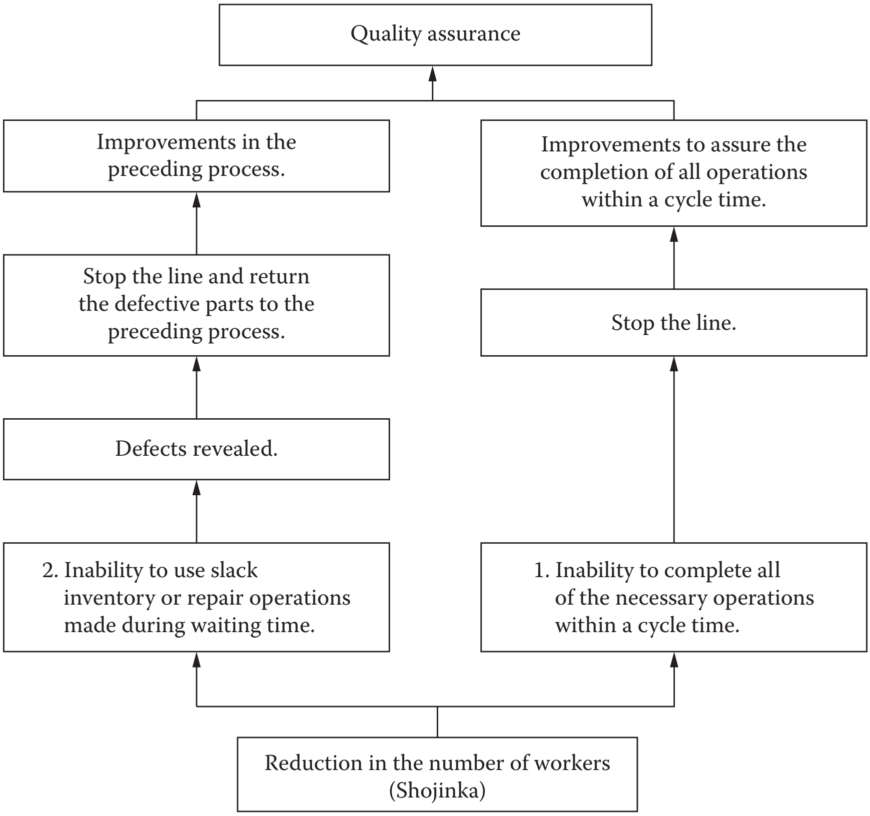


FIGURE 13.5
Causal relationships in line stoppages.

of the defects that have stopped the line. In the case of defective workpieces delivered from the preceding process, for example, he must return the parts to the previous station, investigate the cause of the problem, and, if necessary, institute changes to prevent the defects from occurring again.

The key to preventing defects via human judgment is that every worker has the power to stop the line. In this respect Toyota's production system is not only more effective in controlling quality than Henry Ford's conveyor line, but more humanistic as well.

At Toyota, worker morale is often so high that workers sometimes fail to stop the line when they should, and may even enter the next process to complete their assigned operations; that is, they force themselves to finish their jobs in spite of the supervisor's instructions to stop the line if they are delayed or become tired.

Similar problems may also develop with part-time or seasonal full-time workers who often send products on without installing all of the parts or without fully tightening fasteners. In either case, quality control methods based on human judgment alone may fail as a result of the worker's reluctance to slow production and call attention to himself by stopping the line. A series of devices were installed to stop the line automatically if the worker fails to complete his assigned operation in the allotted time.

Mechanical Checks in Aid of Human Judgment

On one line, for example, the workers carry out their operation while walking along beneath an overhead conveyor. Between processes is a mat like those that open doors automatically in supermarkets and airports. If the worker exceeds the distance allotted for completion of his work, he steps on the mat and the line stops. In a similar operation, the tool used to install lug nuts on wheels is suspended from an overhead rail and moves with the worker as he walks along the line. If the tool holder passes a certain point on the rail, the line stops automatically to prevent the worker from entering the next process to finish his job.

At first, workers resisted even such limited forms of automatic controls because they were forced to complete their jobs within the assigned cycle time. Thus, it was necessary for the supervisors to explain the purpose of the system and its advantages for the worker: to free him from the burden of wasted actions by identifying and correcting various problems in the line. As a result, the workers fully accepted the system, quality control improved, and the total time consumed by line stoppages was actually reduced.

Mistake-Proofing Systems for Stopping the Line

Mistake-proofing systems are similar in operation to the mechanical checks described here and are widely used in both machine and manual operations. Unlike the mechanical checks, however, mistake-proofing systems are used to eliminate defects that may occur due to an oversight on the worker's part, not to lack of time in the cycle or unwillingness to stop the line.

A mistake-proofing system consists of a *detecting* instrument, a *restricting* tool, and a *signaling* device. The detecting instrument senses abnormalities or deviations in the workpiece or the process, the restricting tool stops the line, and the signaling device sounds a buzzer or lights a lamp to attract the worker's attention. In the packing process shown in Figure 13.6, for example, the lift or the product may be damaged if the product is off center on the pallet. To prevent this, a pair of limit switches detects the side-to-side position of the product and a pair of electric eyes checks its position front to rear. If the product is incorrectly positioned, a stopper prevents the pallet from continuing along the line to the lift and a buzzer

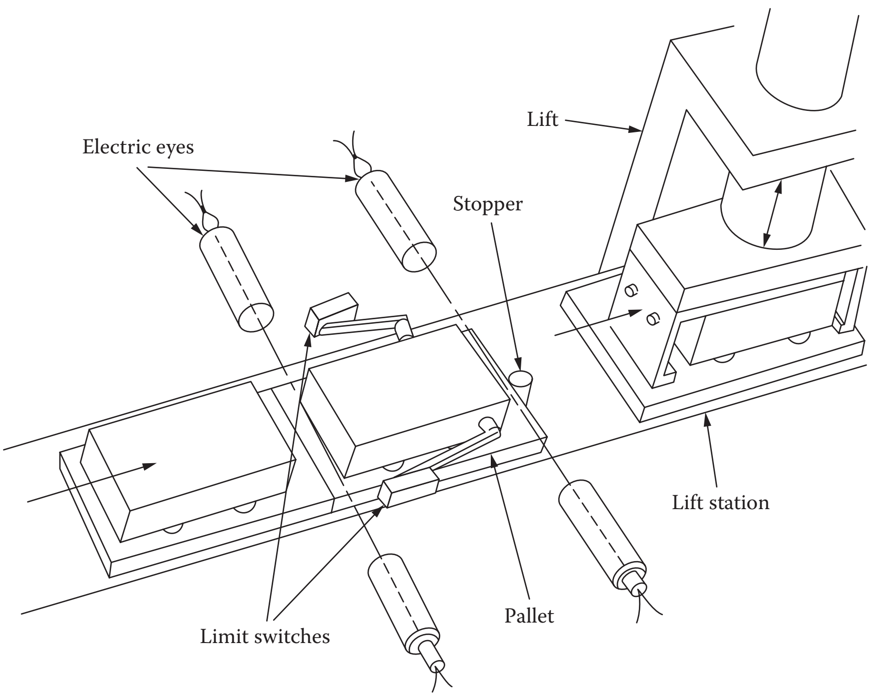


FIGURE 13.6
Contact method (mistake-proofing).

sounds to call the problem to the worker's attention. In this case, the limit switches and electric eyes are the detecting instruments, the stopper is the restricting tool, and the buzzer is the signaling device.

Generally, detecting devices fall into one of three categories and are dictated by the type of mistake-proofing method in use.

Contact Method

Limit switches or electric eyes like the ones shown in Figure 13.6 are used to detect differences in the size or shape of the product and thus to check for the presence of specific types of defects. For the purpose of using the contact method, uniqueness of shape or size is sometimes intentionally designed into essentially similar parts. Devices that distinguish one color from another are also part of the contact method, even though the "contact" is made with reflected light instead of a limit switch or electric eye.

Altogether Method

Unlike the contact method, which is used mainly to check for the presence of a particular feature or to ensure that a specific step has been performed correctly, the altogether method is used to ensure that all parts of an operation have been successfully completed. An altogether system is used, for example, to be sure that the worker puts all of the required parts and an instruction sheet into the shipping box (Figure 13.7). To construct the mistake-proofing device, electric eyes were installed in front of each part bin so that the worker's hand interrupts the light beam when he removes a part or instruction sheet from its bin. Unless all of the beams have been interrupted, the stopper will not release the box and allow it to leave the worker's station.

Other processes controlled by the altogether method use a counter to prevent oversights. At a spot welding station, for example, a counter records the number of welds and sounds a buzzer if there is a discrepancy between the number it has counted and the number required.

Action Step Method

The action step method is so named because, unlike other mistake-proofing methods, it requires the worker to perform a step that is not part of the operations on the product. Consider, for example, the station where metal

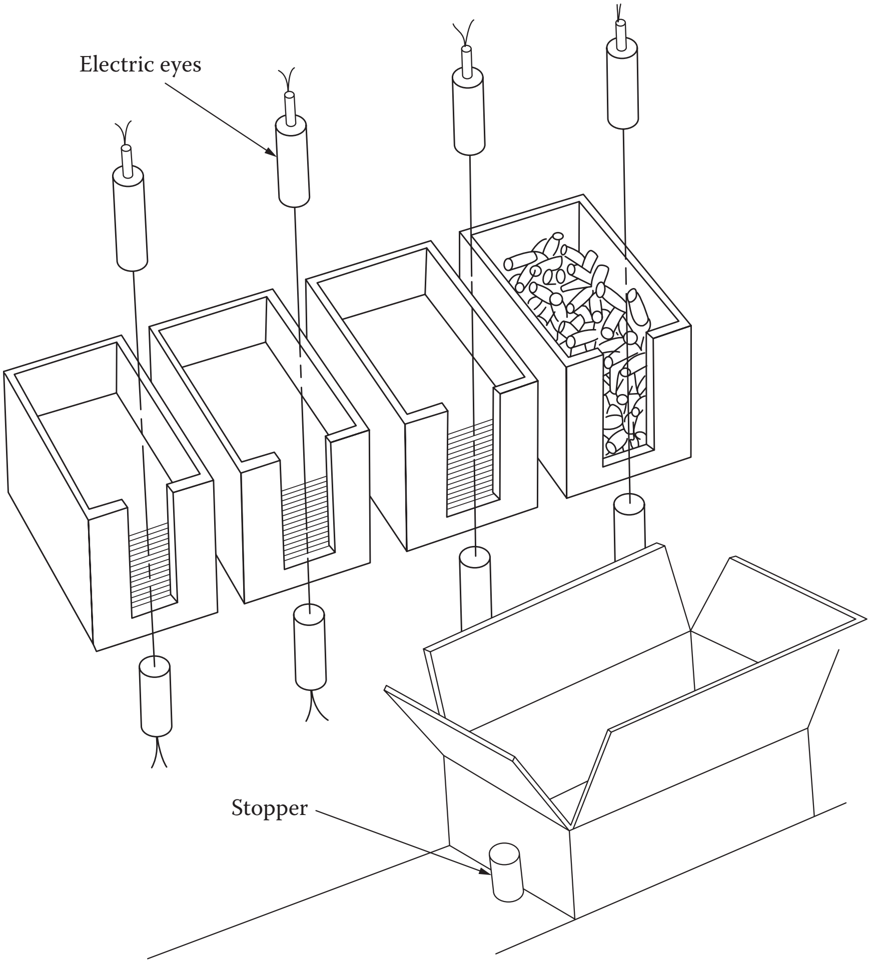


FIGURE 13.7
Altogether method (mistake-proofing).

fittings are attached to seats. Since the same department would often process as many as eight different kinds of seats in a mixed schedule, a kanban was attached to each seat so that the worker would know which metal fittings to attach. Even so, improper metal fittings continued to be installed several times each month. As a result, the following action step mistake-proofing system was devised: kanban attached to seats were designed with an aluminum strip across the bottom which, when inserted in a kanban inserting box, activated a red light over the proper box of metal fittings and opened the box. The worker could then make no mistake in choosing the correct part.

The aforementioned is an example of the advantages of a mistake-proofing system over methods based on human judgment alone. Both methods fulfill the major purposes of autonomation: quality assurance, cost reduction, realization of just-in-time delivery, and increased respect for humanity. Mistake-proofing systems, however, not only guarantee product quality, but contribute to greater respect for humanity by relieving the worker of constant attention to worrisome details.

Visual Controls

In implementing autonomation, various visual controls monitor the state of the line and the flow of production. Some of the visual controls have been mentioned in connection with various types of quality control devices. Most mistake-proofing systems, for example, use a light or some other type of signal to indicate an abnormality in the production run. Other visual controls include andon and call lights, standard operations sheets, kanban tickets, digital display panels, and storage and stock plates.

Andon and Call Lights

Each assembly and machining line is equipped with a call light and an andon board. The call light is used to call for a supervisor, maintenance worker, or general worker. Usually it has several different colors of lights, each of which is used to summon a different type of assistance. On most lines the call light is suspended from the ceiling or otherwise located so that supervisors and maintenance workers can see it easily.

Andon is a nickname for the indicator board that shows when a worker has stopped the line. As explained earlier, each worker at Toyota has a switch that enables him to stop the line in the event of a breakdown or a delay at his station. When this happens, a red lamp on the andon over his line will light to indicate which process is responsible for the stoppage. The supervisor then goes immediately to the workstation to investigate the problem and take the necessary corrective action. Figure 13.8 shows a call light and andon boards with the switch used to control the lamps. In the figure, the call lights are mounted on the andon; at some stations, however, the two are installed at separate locations (Figure 13.9).

In many cases, the andon has different colored lights to indicate the condition of the line. A green light, for example, indicates normal operation, a yellow light indicates that a worker is calling for help with a problem. If the

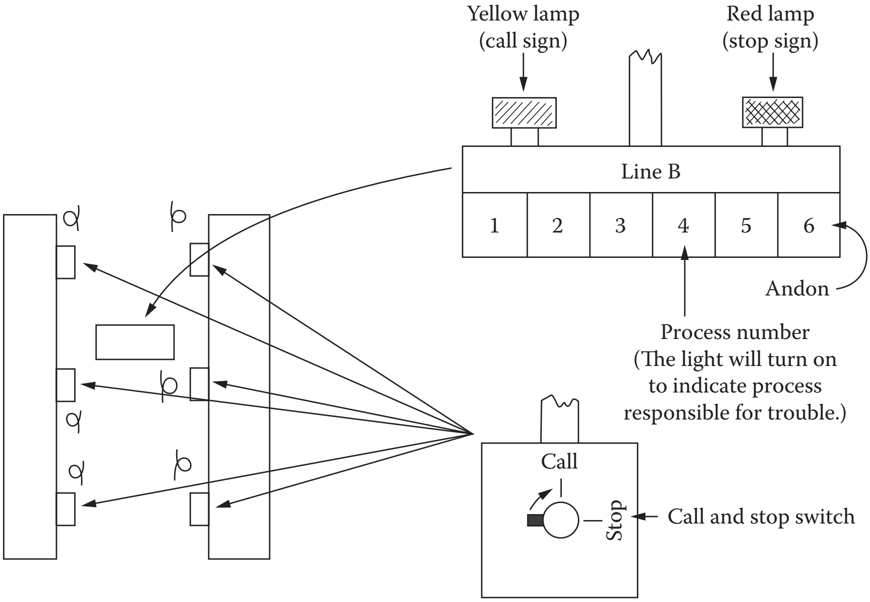


FIGURE 13.8
Call light, andon, and stop switch.

trouble is not corrected, a red light will come on to show that the line has stopped. At other locations, andon boards may have even more lights and use a different color code to indicate the condition of the line. The board usually has five colors with the following meanings:

Red	Machine trouble
White	End of a production run; the required quantity has been produced
Green	No work due to shortage of materials
Blue	Defective unit
Yellow	Setup required (includes tool changes, etc.)

All types of andons are turned off when a supervisor or maintenance person arrives at the workstation responsible for the delay.

Standard Operations Sheets and Kanban Tickets

As explained in Chapter 10, a standard operation at Toyota consists of a cycle time; a standard operations routine, including assigned checks for quality and safety; and a standard quantity of work-in-process. All three

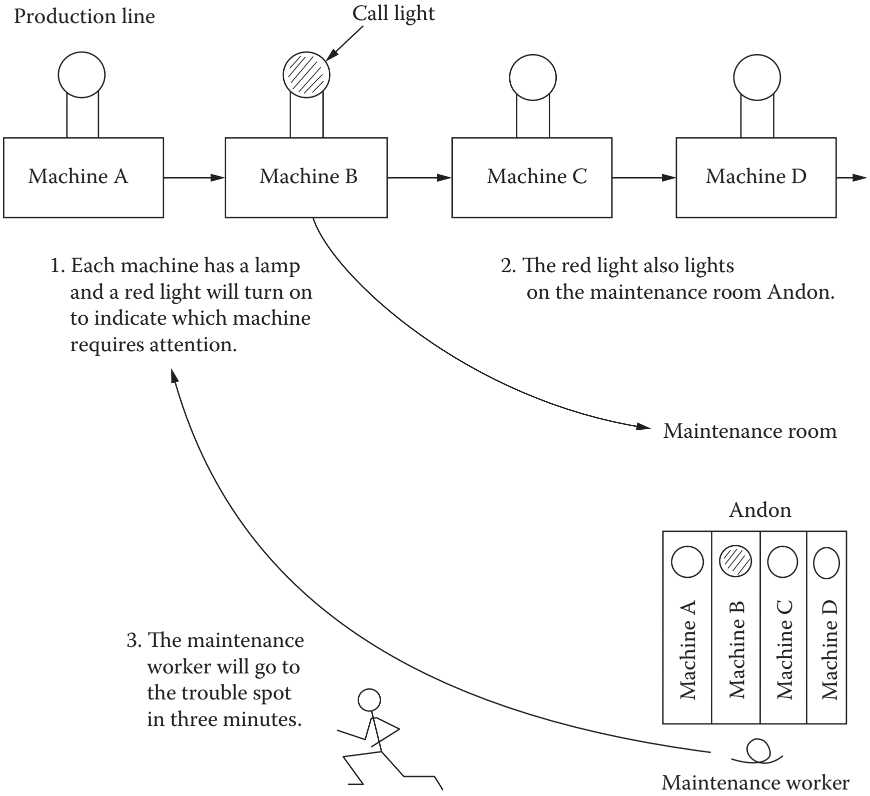


FIGURE 13.9
Machine-maintenance andon.

of these elements are included in a standard operations sheet, which is posted at the line where each worker can easily see it. When a worker cannot perform his standard operations within the cycle time, he must stop the line and call for help to resolve the problem. The standard operations sheet thus works together with other types of visual controls to achieve standard operations, eliminate waste, and prevent defects.

Like the standard operations sheet, kanban tickets also serve as a visual control over abnormalities in production. If, for example, products find their way into the storage area behind the line with no kanban attached, it is a sign of overproduction that should be investigated immediately. Either the cycle time has been set too long, or the worker has excessive waiting time, or the line has been stopped frequently at the next process. In any case, the absence of the kanban should act as a signal for immediate investigation and elimination of the problem.

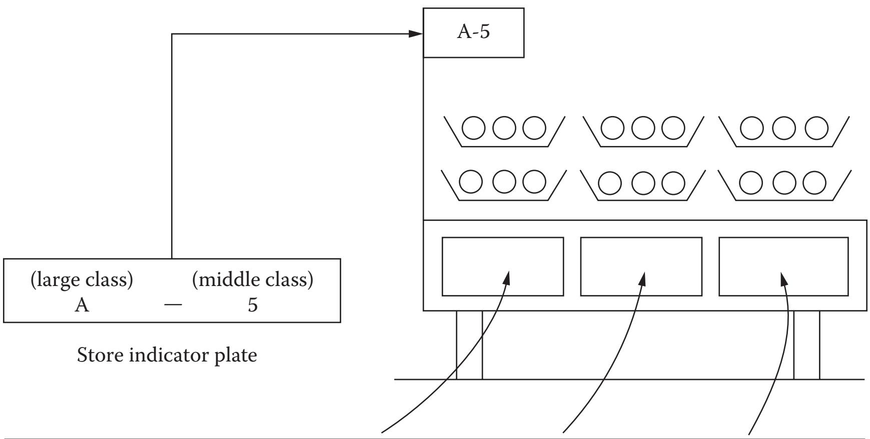
In addition to their role in overproduction control, kanban tickets serve other visual control functions as well. By checking the number of the production ordering kanban, for example, the supervisor can tell which products are in process and determine whether overtime will be necessary or not.

Digital Display Panels

The pace of production is also shown in digital display panels, which indicate both the day's production goal and a running count of the units produced so far. Thus, by watching the panels, everyone on the line can tell whether production is going too slowly to meet the day's goal and can work together to keep production on schedule. Like call lights and andons, the digital display plates also serve to alert supervisors to problems and delays at various points along the line.

Store and Stock Indicator Plates

Each storage location is assigned an "address" which is shown both on a plate over the storage location (Figure 13.10) and on the kanban. As a result, carriers can always deliver parts to the proper location by comparing the address on the kanban to that on the store plate. In addition to



Back number	Type	Item number	Stock address	Standard quant. of stock
110	13S	3111-4751-04	A-5-1	3 boxes

FIGURE 13.10
Store plate and stock plate.

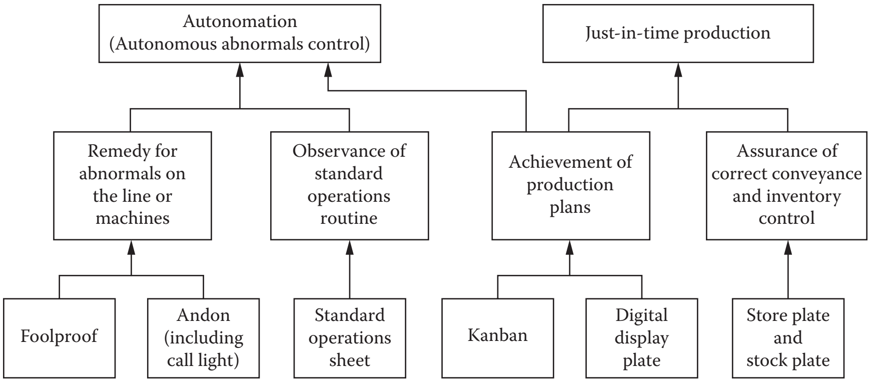


FIGURE 13.11
Framework of the visual control systems.

the storage address, the stock plate also indicates the standard quantity of stock as an aid to inventory control.

While visual control systems are effective in achieving autonomation, they, like other quality control methods, function only to detect abnormalities (Figure 13.11). Remedial action to correct the defects or abnormalities remains in the hands of the supervisor and his workers, who must always follow a prescribed sequence of events: standardization of operations, detection of abnormalities, investigation of causes, improvement activities through QC circles, and restandardization of operations. Ultimately, however, the goal of autonomation must be unmanned production, where even remedial action to correct defects is taken autonomously. Before going on to examine other types of quality control, it may be useful to look at robotics—its use and its potential impact on the Toyota Production System.

§ 5 ROBOTICS

Like their American counterparts, Japanese automobile manufacturers are installing industrial robots on a large scale, especially in processes that involve welding, painting, and machining of parts. The reasons are many, including: increased safety, increased product quality, and increased productivity with, of course, reduced costs. Where safety and product quality are concerned, the advantages of robotics are obvious. Robots can relieve human workers of hazardous jobs in areas where they are exposed to dangerous fumes and other environmental threats. Since robots can perform repetitious operations with high accuracy and without fatigue, they also contribute to improved quality control. Increased productivity, on the other hand, is less simple to assess.

At present, a skilled laborer in Japan earns about 4 million yen per year with annual increases of approximately 6 to 7 percent. While wages continue to rise, the cost of the simplest robot is approximately two million yen. Even the most complex robots can be purchased for 15 to 20 million yen. Since a painting robot, for example, can do the work of 1.5 men, the long-term savings in labor costs from robotics are obvious and hard to ignore. In addition, robots are more easily adaptable to increased product diversity than a human labor force since they require fewer changes in the layout of processes when designs change. A production system composed of robots and machines, for example, can often be adapted to new models simply by a change in tools and a change in the robot's memory. With men-machine systems, on the other hand, a model change often involves large investments in new equipment and training for human operators.

Robots and the Toyota Production System

Whatever the impact of robotics on employee relations, it is important to see that its introduction is not an abandonment but a logical extension of the Toyota Production System. In fact, the principal goals of robotics are fully in keeping with those of the system, which are, in general, cost reduction, quality assurance, flexible production, and respect for humanity. How robotics contributes to the first three goals has already been described. Its contribution to respect for humanity is not only to relieve human workers of risky, severe jobs but to extend in various ways the prevailing use of machines and technology in the Toyota Production System—namely, to replace men with machines only when it will free the worker from repetitive tasks and make more time available for meaningful human action. In short, robots, like any other kind of technology must remain the tool of men and not the other way around.

§ 6 COMPANY-WIDE QUALITY CONTROL

The phrase Total Quality Control (TQC) was first used by Dr. Feigenbaum of the United States in *Industrial Quality Control* magazine (May 1957).

According to Feigenbaum, all departments of a company, including marketing, design, production, inspection, and delivery must participate in QC.

Feigenbaum assigns the central role in promoting TQC to QC specialists. Japanese TQC, however, which is often called Company-Wide Quality Control (CWQC) to distinguish it from Feigenbaum's TQC, is not conducted by QC specialists. If it were, line employees in each department would very likely reject the suggestions of the QC staff because line connections are very strong in Japanese companies. Instead, QC is the responsibility of workers at every level and in every department of the organization, all of whom have studied QC techniques.

According to Dr. Kaoru Ishikawa, promoter of the Japanese QC movement, CWQC has the following three characteristics: all departments participate in QC, all types of employees participate in QC, and QC is fully integrated with other related company functions.

All Departments Participate in QC

To assure product quality, all departments—product planning, design, testing, purchasing, suppliers, manufacturing engineering, inspection, sales, service, etc.—must participate in QC activities. Quality analyses at the product development and product design stages, for example, are essential to establishing overall product quality, since it is impossible to correct errors made at either stage once the product reaches manufacturing and inspection departments. At the same time, however, each of the other departments also has an important role of its own to play. At this point, it may be useful to recall the definition of quality control with which the chapter began: in Japan, quality control (QC) or quality assurance (QA) is defined as the development, design, manufacture, and service of products that will satisfy the consumer's needs at the lowest possible cost.

Satisfaction of the consumer's needs is predominantly the concern of new product development and design, which must identify customer needs, such as high gas mileage and trouble-free performance, and be sure that the product satisfies them. Quality control at this level ensures that the Japanese automobile will continue to be popular throughout the world and thus, ultimately, that sales and profits will continue to be high. Quality control during manufacturing (through autonomation and other techniques described in this chapter) decreases production costs by reducing defects and thus guarantees both low cost to the consumer and company profitability. And finally, quality control in customer service in the aftermarket is important for maintaining the automobile in good working order, thereby confirming the customer's confidence in the product and in the company. The same points are made in pamphlets issued by Toyota Motor Sales, USA.

All Employees Participate in QC

People at all levels of the organizational hierarchy participate in quality control—from the president of the company, the directors, and departmental managers to blue collar workers and salesmen. Furthermore, all suppliers, distributors, and other related companies also take part in QC activities.

Although the term *QC circle* is very popular in other countries, it should be recognized that QC circle activities are merely a part of CWQC. Without CWQC and without the obvious participation of top management, departmental managers, and their staffs, QC circles would lose much of their effectiveness and might cease to exist altogether.

QC Is Fully Integrated with Other Related Company Functions

To be effective, quality control must be promoted together with cost management and production management techniques. These include profit planning, pricing, production and inventory control, and scheduling, each of which has a direct impact on quality control. Cost control techniques, for example, can help identify wasteful processes that can be improved or eliminated and can measure the effect of QC activities once undertaken. Pricing determines not only the level of quality built into the product but the customer's expectations about quality as well. And various kinds of production control data can be used to measure defect rates, establish target areas for QC activities, and promote QC in general.

14

Cross-Functional Management to Promote Company-Wide Quality Assurance and Cost Management

§ 1 INTRODUCTION

As described in Chapter 13, CWQC is possible only if quality control activities and quality-related functions are carried out in all departments and at all levels of management. Furthermore, the activities of each department must be planned so they are reinforced by other departments. Additionally, they will benefit from quality-related functions throughout the company. The responsibility for establishing communication links between the various departments at Toyota and ensuring cooperation in implementing QC programs is given to an organizational entity known as a *functional meeting*. Functional meetings do not serve as project teams or task forces. Rather, they are formally constituted, decision-making units whose power cuts across department lines and controls broad corporate functions. Consisting typically of department directors from all parts of the company, each functional meeting will consider such corporate-wide problems as cost management, production management, and quality assurance, respectively. The meeting participants then communicate their policy decision and plans for implementation to each department for action. Such management through functional meetings is called *functional management* (*Kinohbetsu Kanri*) at Toyota.

However, the English term *functional management* is a literal translation of the Japanese term *Kinohbetsu Kanri* used at Toyota. Although *Kinoh* implies *function*, Toyota uses this word to mean any *company-wide role*, as opposed to its usual association with the function of each department, such as development, manufacturing, sales, and so on, in the company.

The term *cross-functional management* is often used in the business world, covering various functional departments such as development, manufacturing, sales, and the like. Thus what is called *functional management* at Toyota signifies *cross-functional management* in ordinary terminology. In other words, Toyota's functional management may be paraphrased as *cross-departmental management*.

In this chapter, we will examine the structural relationships between the functional meetings and the more formally developed organizations at Toyota, how business policy is made and administered through functional management, and some of the advantages to be gained from the functional management concept. Although the Toyota Production System in a narrow sense does not include the product planning and design steps, the author includes functional management in the broad overview of the system. The reader should realize that the most important aspects for increasing productivity or decreasing costs and improving quality are the QC and cost reduction activities in the product development and design steps.

Historically, functional management is the outgrowth of a long process of trial and error. The QC Promoting Office at Toyota took the first steps toward CWQC in 1961 by defining various important functions to be performed by the company. Each department, in turn, collaborated to determine and arrange the contents of the functions. By the addition, integration, and abolition of these inputs, the defined functions were classified and selected into the two most necessary rules for the entire company: quality assurance and cost management. Rules were then established to define what kinds of activities each department must undertake to properly perform these two functions.

§ 2 QUALITY ASSURANCE

Quality assurance, as defined in this rule at Toyota, is to assure that the quality of the product promotes satisfaction, reliability, and economy for the consumer. This rule outlines the activities of each department for quality assurance at all phases from product planning to sales and service. Further, the rule specifies *when* and *what* should be assured by *whom at where*.

The rule defines *when* as eight applicable steps in a series of business activities from planning through sales. The eight steps are as follows:

- Product planning
- Product design
- Manufacturing preparation
- Purchasing
- Manufacturing for sales
- Inspection
- Sales and service
- Quality audit

The term by *whom at where* means the specific department manager and the name of his department. *What* consists of items to be assured and the operations for assurance. Table 14.1 defines the quality assurance rule as it pertains to the steps in the business activities defined here and the primary operations of each department.

§ 3 COST MANAGEMENT

Toyota utilizes cost management to develop and perform various activities to attain a specific profit goal, evaluate results, and take appropriate action as necessary. In other words, cost management is not simply confined to cost reduction. It also covers company-wide activities to acquire profit. This rule specifically outlines the activities of each department level to maintain cost management. The framework of this cost management evolves from the following four categories: target costing, capital investment planning, cost maintenance, and cost improvement (or *kaizen costing*).

Target costing has been regarded as especially important because most of the cost is determined during the development stages of the product. A cost planning manual assigns primary responsibilities and tasks at each phase of product development. Establishing a target cost to be followed during all development stages promotes activities to reduce costs, while maintaining minimum quality standards.

Cost maintenance and cost improvement (*kaizen costing*) are cost management processes at the manufacturing level. These are promoted by a company-wide budgeting system and the improvement activities to be described in Chapter 15. To maintain these functions, each department has its own departmental budgeting manual and cost improvement manual.

TABLE 14.1

Quality Assurance Summary

Functional Steps	Person in Charge	Primary Operations for QA	Contribution
Product Planning	Sales department manager	1. Forecasts of demands and market share	Δ
	Product planning department head	2. Obtain the quality to satisfy marketing needs	
		a. Set and assign proper quality target and cost target.	⊙
		b. Prevent recurrence of important quality problems.	⊙
Product Design	Design department manager	1. Design of prototype vehicles	
	Body-design department manager	a. Meet quality target	⊙
	Engineering department managers	b. Test and examine car for:	O
	Product design department manager	Performance	
		Safety	
		Low Pollution	
		Economy	
		Reliability	
		2. Initial design to confirm necessary conditions for QA	O
Manufacturing Preparation	Engineering department managers	1. Preparation of overall lines to satisfy design quality	⊙
	QA department manager	2. Preparation of proper inspection methods	O
	Inspection department managers	3. Evaluation of initial prototypes	O
	Manufacturing department manager	4. Develop and evaluate a plan of initial and daily process control	Δ
		5. Preparation of line capacities	⊙

Purchasing	Purchasing department managers QA department manager Inspection department managers	1. Confirmation of qualitative and quantitative capabilities of each supplier	Δ
		2. Inspect initial parts supplied for product quality	Δ
		3. Support in strengthening QA system of each supplier	Δ
Manufacturing	Manufacturing department managers Production control department manager	1. Match product quality to established standards	O
		2. Establish properly controlled lines	O
		3. Maintain necessary line capacities and machine capacities	O
Inspection	Inspection department manager QA department manager	1. Inspect initial product for quality	O
		2. Decision whether to deliver product for sale	⊙
Sales and Service	Sales department manager Export department manager QA department manager	1. Prevention of quality decline in packaging, storage, and delivery	O
		2. Education and public relations for proper care and maintenance	Δ
		3. Inspection of new cars	Δ
		4. Feedback and analysis of quality information	Δ

The contents of cost management activities are specified in detail in the cost management operations assignment manual. Table 14.2 summarizes the cost management rule with respect to related departments and cost management operations.

Relations among Departments, Steps in Business Activities, and Functions

To effectively promote functional management, it must be clearly understood how each step to be performed by each department contributes to its function. Because equal emphasis cannot be placed on all operations, each step must be graded for relative contribution. Thus, the right-hand column in Tables 14.1 and 14.2 describes the relative contribution for each managerial function, as noted by the following symbols:

- ⊙ Defines factors with critical influence on the function
- O Defines factors with some influence that could be remedied in later steps
- Δ Defines factors with relatively small influence

Such assessments were made for all functions. The relationships between departments and functions are summarized in Table 14.3.

The final business purpose at Toyota is to maximize long-range profit under various economic and environmental constraints. This long-range profit will be defined and expressed as a concrete figure through long-range business planning. Therefore, each function must be carefully selected and organized to be helpful in attaining the long-range profit.

If the number of functions is too high, then each function will begin to interfere with other functions, frustrating attempts to produce a new product in a timely and cost effective manner. Further, too many functions will foster strong independence of certain functions to the point that each departmental manager might be enough to perform the function.

Conversely, if the number of functions is too small, too many departments will be related in a single function. Managing so many departments from a certain functional standpoint would be very complicated, if not impossible.

Toyota regards quality assurance and cost management as paramount functions, or *purpose functions*, and calls them the two pillars of functional management. Other functions are regarded as *means functions*. Thus, product planning and product design are integrated into an engineering function; manufacturing preparation and manufacturing into a production function; and sales and purchasing into a business function.

As a result, six functions remain in the Toyota functional management system (Table 14.3). In summary, each function in new product development, manufacturing technique, and marketing philosophy is not identical with other functions in its character or priority.

§ 4 ORGANIZATION OF THE CROSS-FUNCTIONAL MANAGEMENT SYSTEM

At Toyota, each director of the company is responsible for a certain department. Since each department involves more than one function, each director must participate in multiple functions (Table 14.3). No single director is responsible for a single function; he serves as a member of a team. Conversely, not all department directors participate in all functions. This would create difficulties managing each functional meeting because of too many members. For example, although there are thirteen departments involved in product planning and product design, only one or two directors will attend a QA functional meeting.

As previously stated, the functional meeting is the only formal organizational unit in functional management. Each functional meeting is a chartered decision-making unit charged to plan, check, and decide remedial actions required to achieve a functional goal. Each individual department serves as a line unit to perform the actions dictated by the functional meeting.

Figure 14.1 details the framework of the top management organization at Toyota. Each department is managed by a managing director or common director, whereas each functional meeting consists of all directors, including six executive directors. Since each executive director is responsible for integrating the actions of various departments, he will participate as chairman in those functional meetings that have close relationships with his integrated departments. By necessity, even a vice president may participate in a functional meeting. A functional meeting typically numbers about ten members.

The quality assurance and cost management functional meetings are normally conducted once a month. Other functional meetings are usually

TABLE 14.2

Cost Management Summary

Functional Steps	Related Departments	Cost Management Operations	Contribution
Product Planning	Corporate planning Product planning office	1. Set target cost based on new product planning and profit planning, then assign this target cost to various cost factors	⊙
	Production engineering departments	2. Set target investment figures	⊙
	Accounting departments	3. Allocate target cost to various design departments of individual parts (*cost planning*)	O
		4. Allocate target investment amounts to various investment planning departments (*capital budgeting*)	O
Product Design	Product planning office	1. Cost estimate based on prototype drawing	⊙
	Engineering departments	2. Evaluate possibility of attaining target costs	⊙
		3. Take necessary steps to minimize deviations between target costs and estimated costs through Value Engineering (VE)	O
Manufacturing Preparation	Product planning office	1. Establish cost estimate by considering line preparation and investment plans	⊙
	Engineering departments	2. Evaluate possibility of attaining target costs	⊙
	Manufacturing engineering departments	3. Take actions to minimize deviations	⊙
		4. Evaluate facilities investment plans	O
	Production control department	5. Evaluate production plans, conditions, and decisions to make or buy parts	O

Purchasing	Purchasing departments	1. Evaluate procurement plans and purchasing conditions	O
		2. Establish control of supplier prices (comparison of target reduction and actual reduction amounts, analyze variances and take appropriate action)	O
		3. Investigate improvement of supplier costs (apply Value Analysis (VA), establish support to promote supplier cost improvement activities)	⊙
Manufacturing Inspection	Related departments Accounting department	1. Instigate cost maintenance and improvements through:	
		a. Budgeting fixed costs (Manufacturing and Managerial Departments)	O
		b. Cost improvements in primary projects (classified for each type of vehicle and cost factor)	O
		c. Increased cost consciousness of employees through suggestions systems, case presentation seminars, reward or incentive programs, etc.	⊙
Sales and Service	Related departments Accounting department	1. Measure actual costs of new products through overall evaluation	O
		2. Participate in analyses and discussions at operations check, cost management functional meetings, cost meetings, and various committee meetings	O

TABLE 14.3

Summary of Various Functional Managements

Business Activity	Related Departments	Quality	Cost	Engineering	Production	Business	Personnel	
		Functions						
Product Planning	Product planning department	⊙	⊙	O	Δ	⊙	O	→ Departmental Management
	Engineering planning department							
Product Design	Laboratory	⊙	O	⊙	O	O	O	→
	Design department							
Manufacturing Preparation	Manufacturing engineering department	⊙	⊙	O	⊙	Δ	O	→
	Manufacturing planning department							
Purchasing	Purchasing department	⊙	⊙	Δ	Δ	Δ	O	→
	Purchasing management department							
Manufacturing	Motomachi plant	⊙	O	Δ	⊙	O	⊙	→
	Honshu plant							
Sales	Sales department	⊙	O	O	O	⊙	O	→
	Export department							
		↓	↓	↓	↓	↓	↓	
		Functional Management						

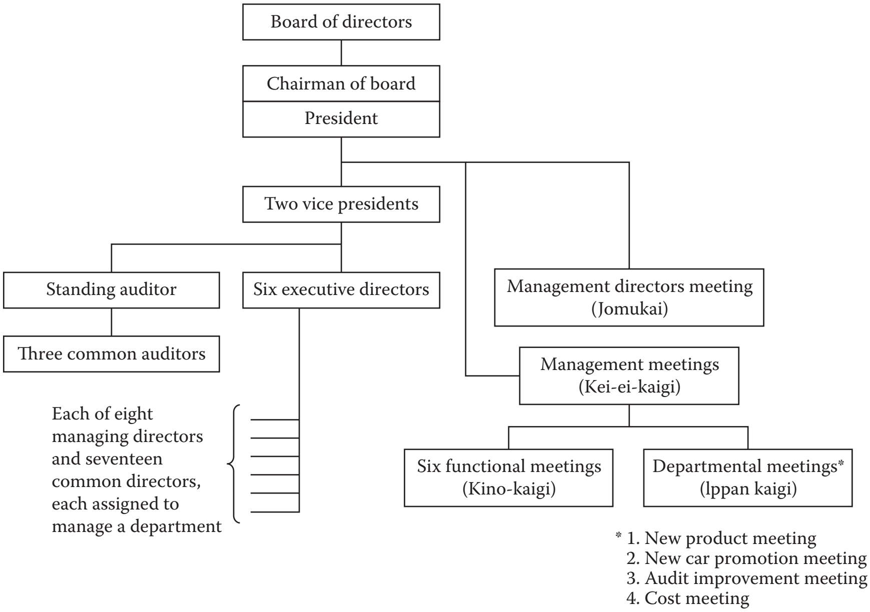


FIGURE 14.1
Framework of Toyota management organization (as of 1981).

held every other month. A functional meeting should not be convened without a significant agenda.

Functional meetings are positioned below the management meeting, which consists of all managing directors and the standing auditor. The management meeting is an executive organization that gives final approval to the decision items of the functional meeting. However, the essential decision-making authority remains with each functional meeting because implementation of the decision begins at the functional meeting. As long as there are no special objections in the management meeting, the decision made by the functional meeting will be treated as a company decision.

The *departmental meetings* shown in Figure 14.1 provide each department with a vehicle to discuss implementation of decisions made by the functional meeting. Note that the departmental meeting is not positioned as a substructure of the functional meeting. As with the functional meetings, plans for implementation generated within departmental meetings are subject to review and approval by the management meeting.

Occasionally, a problem arises such as a need to achieve a certain quality characteristic within a short-term period that cannot be resolved by only one functional meeting. By necessity, man-hours and costs must increase to improve the quality. At this time, a *joint functional meeting* is found to combine quality and production functions. Further, to cope with a new legal restriction for safety and pollution, most of the functions, such as QA, cost, engineering, and production, must consider the restriction together. In this case, an *enlarged functional meeting* is formed to consider the problem. Note that these are not permanent organizational entities.

Another example involves a *cost management functional meeting.* Just after the oil shock in 1973, the profitability of the Toyota Corolla showed a marked decrease because of cost increases due to oil prices. At that time, the plant manager of Corolla made the following proposals to the cost functional meeting:

1. Promotion of a company-wide cost reduction movement for Corolla.
2. Organization of a Corolla Cost Reduction Committee chaired by the plant manager.
3. As substructures to this committee, organization of the following sectional meetings:
   a. Production and assembly
   b. Design and engineering
   c. Purchasing
4. Establish a cost reduction of 10,000 yen (about $80) per automobile.
5. Goal to be achieved within six months.

Through a concerted effort by all departments based on the decisions of the cost management function meeting, the actual result of the plan was 128 percent attainment of the goal at the end of six months (May 1975).

Business Policy and Functional Management

Since the introduction of the CWQC concept, a business policy has been developed and published. The policy applies to the operations level and includes each function previously discussed. The six elements of the business policy are shown in Figure 14.2 and defined in the following paragraphs.

1. *Fundamental policy* is the business ethic principle, or fundamental directions, of the company. Once established, it will not change for many years. An example is “Toyota wishes to develop in the world by

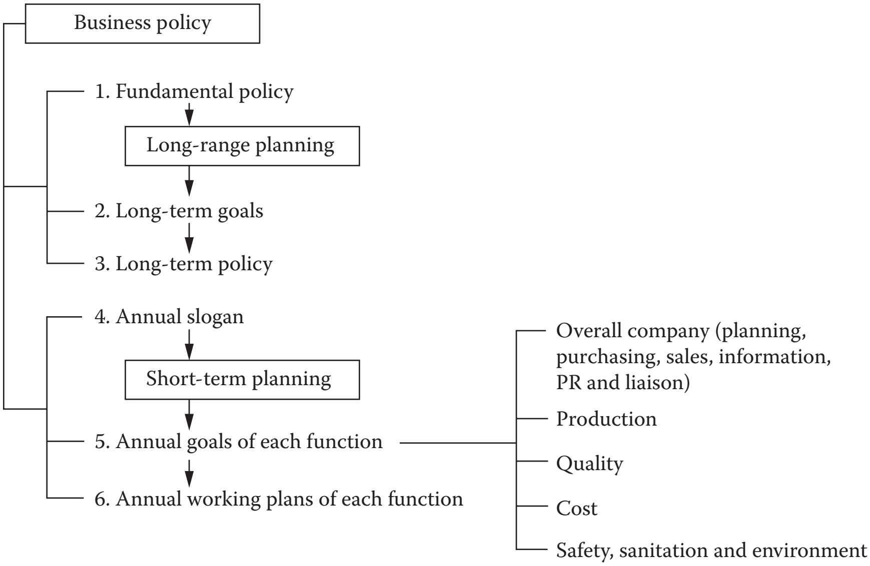


FIGURE 14.2
Six elements of business policy at Toyota.

collecting all powers inside and outside the company." The expression is abstract, but represents a business philosophy of top management. The fundamental policy is used to guide long-range planning.

2. *Long-term goals* are goals to be attained within five years as an output of long-range planning. These goals are concrete figures expressed for production quality, sales quality, market share, ROI, and so on.
3. *Long-term policy* is the strategy used to achieve the long-term goals, and is expressed in more concrete detail than the fundamental policy. It covers several items common to the overall company. For example: "In order to manage the overall company in a scientific manner, policies, goals, and plans must be prepared for each department and a control point must be clearly defined and directed."
4. *Annual slogan* is a means for Toyota to emphasize annual policies. It consists of two types of slogans. The first type remains the same every year, such as "Assure the quality in every Toyota." The second type emphasizes the policy for the year. For example, the slogan for 1974 just after the oil shock was "Build Toyotas for the changing age." Also: "It is time to use scarce resources effectively." The purpose of these slogans is to encourage a sound mental attitude in all employees.

5. Accepting the long-term goals described above, the *annual goals of each function* to be achieved within the current year must be expressed in specific figures. These goal figures are established for each function. Each functional meeting, in turn, decides how to achieve these goals. The items included as annual goals for each function follow:
   a. Overall company: ROI, production quantity, and market share.
   b. Production: Rate of reduced manpower to previous year's manpower level.
   c. Quality: Rate of reduction of problems in market.
   d. Cost: Total amount of costs to be reduced, plant and equipment investment amount, and margin rates of the preferentially developed automobiles.
   e. Safety, sanitation, and environment: Number of closures for holidays, and so on, at business and plants.
6. Once annual goals are established for each function, *annual working plans of each function* must be determined by the appropriate functional meeting. Implementation of these working plans then becomes the responsibility of the department meeting.

Classification of the functions shown in Figure 14.2 is somewhat different than shown in Table 14.3 because the business policy must describe all the important topics to be achieved in the current year. The business function in Table 14.3 is incorporated into the overall company function shown in Figure 14.2, which also includes information and public relations. Further, although the safety, sanitation, and environment functions are not shown in Table 14.3, nor is there a functional meeting, safety and environment are included with the production functional meeting, while sanitation is included with both the production and personnel functions.

Business Policy Development

Formal announcement of the business policy at Toyota is made by the president in his New Year's greetings to the employees. Development plans of each function will then be issued to each department by the office of the functional meeting. Department policies and plans are then formulated by the department meeting.

After implementation of these plans, the results of actual performance will be evaluated during the middle and at the end of the current year.

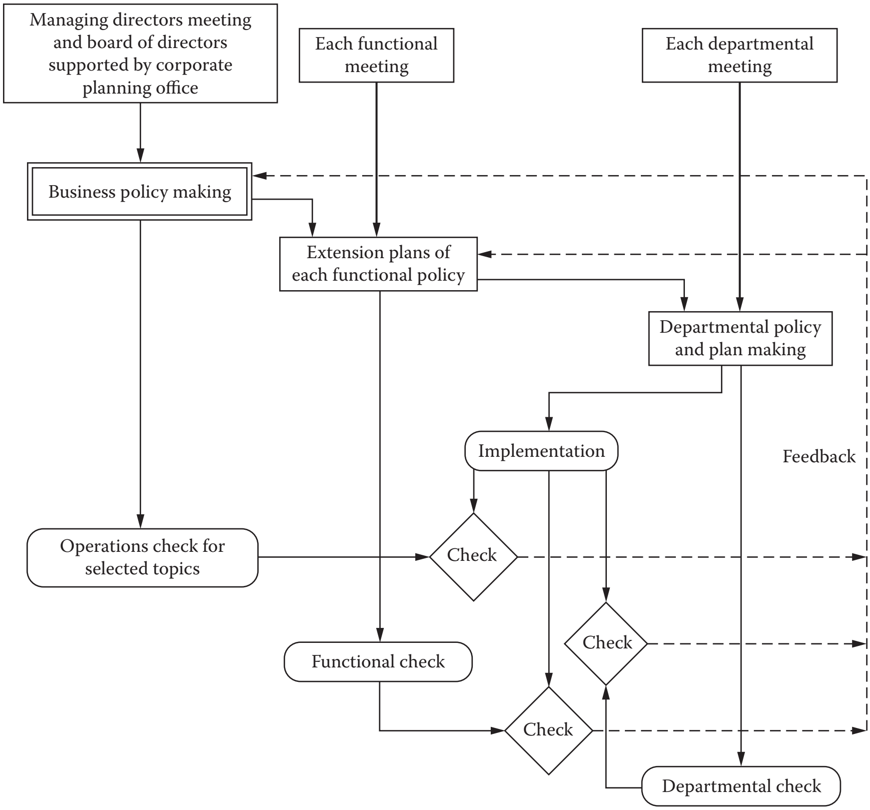


FIGURE 14.3
Toyota planning and control system.

Feedback from these evaluations will be used to form the policies for the next year. Such checks and evaluations are made at three levels within the organization: operations checks of selected topics by top management, functional checks by each functional meeting chairman, and department checks by each department manager or director. Figure 14.3 shows the organization planning and control system employed at Toyota.

Critical Considerations for Functional Management

Four critical considerations demand special attention in order to achieve a successful functional management program:

1. Selection of important functions should be made using special caution to properly balance department participation. Having too many

departments in the same functional meeting leads to confusion and difficulties in managing the meeting; too few member departments creates a need for many individual functions that will begin to overlap responsibilities, again creating confusion and management problems.
2. Functional management should not be regarded as an informal system. The position and guidelines of functional meetings in the top management scheme must be clearly defined. The function meeting must be given the necessary authority to implement its decisions as company policy.
3. Each line department must have a strong structure in place to execute the plans put forth by the various functional meetings.
4. The director in charge of each function is also responsible for an individual department. However, he must not view the function for his department alone, but rather formulate and direct the function for the overall company.

Advantages of Functional Management

Functional management as implemented at Toyota offers certain advantages not found in other management systems. For example:

- Both policies and implementation are decisive and rapidly instituted. This results because the functional meeting is a substantial decision-making entity with responsibilities and authority directed from top management. Additionally, communication to executing line departments is rapid since the members of the functional meeting are also directors responsible for the related departments.
- *Nemawashi* is unnecessary at Toyota. The original meaning of Nemawashi comes from the preparations for transplanting a large tree. You must dig around the roots and cut the big roots to influence small roots to run and secure new positions. Nemawashi, as applied to business, relates to the persuasion of related individuals, such as management executives, to accept a proposal before a formal decision meeting. At Toyota, the functional meeting itself becomes the Nemawashi negotiation.
- The functional meetings serve to greatly enhance communications and human relations among various departments because all sides are brought together to achieve a common goal.

- Communications from subordinate employees to the functional meetings are easily achieved because there is no need for Nemawashi. These employees need only to bring their suggestions and ideas to their department manager for discussion at the functional meeting.

15

Kaizen Costing

§ 1 CONCEPT OF KAIZEN COSTING

Kaizen costing in Japanese automobile companies has not been implemented in accordance with standard costing. This means that companies do not use traditional cost variance analysis based upon the gap between standard cost and actual cost for each period. Kaizen costing is implemented outside the standard cost system as part of the overall budget control system. In essence, the actual cost per car for the most recent period is the kaizen cost budget, which must be reduced in each successive period to meet the target profit.

The reason why Japanese automobile companies implement kaizen costing outside the standard cost accounting system is not that cost reduction in the production stage is taken less seriously, but that it is considered to be very important. Standard costing is limited by its financial accounting purpose in Japanese automobile companies and therefore it has many features that are unsuitable for cost reduction in the manufacturing phase.

Further, the concept of kaizen costing covers a broader scope than the traditional cost control concept, which focuses on meeting cost performance standards and investigating and responding when those standards are not met. Kaizen costing activities include cost reduction activities that require changes in the way the company manufactures existing products. The inadequacy of standard costs for kaizen costing purposes is obvious from the viewpoint of "kaizen" concepts.[1] Also, standard costs are changed only once a year. (See Figure 15.1.)

[1] See Imai (1986), Chapter 2. In the glossary, Imai defines the meaning of kaizen as follows: kaizen means continuing improvement in personal life, home life, social life, and working life. When applied to the workplace kaizen means continuing improvement involving everyone—managers and workers alike. Further, he says, improvement can be defined as kaizen and innovation, where a kaizen strategy maintains and improves the working standard through small, gradual improvements, and innovation calls forth radical improvements as a result of large investments in technology and/or equipment.

Standard Costing Concepts	Kaizen Costing Concepts
Cost control system concept	Cost reduction system concept
Assume current manufacturing conditions	Assume continuous improvement in manufacturing
Meet cost performance standards	Achieve cost reduction targets
Standard Costing Techniques	**Kaizen Costing Techniques**
Standards are set annually or semiannually	Cost reduction targets are set and applied monthly Continuous improvement (kaizen) is implemented during the year to attain target profit or to reduce the gap between target profit and estimated profit
Cost variance analysis involving standard costs and actual costs	Cost variance analysis involving target kaizen costs and actual cost reduction amounts
Investigate and respond when standards are not met	Investigate and respond when target kaizen amounts are not attained

FIGURE 15.1
Standard vs. kaizen costing.

§ 2 TWO TYPES OF KAIZEN COSTING

Roughly classified, kaizen costing activities are of two kinds. The first, *kaizen costing for a specific product,* consists of activities to improve performance when the difference between actual cost and target cost is large after new products have been in production for three months, or when the cost of a specific model must be reduced remarkably because of a sudden market downturn or similar circumstance. The second type consists of activities implemented continually every period to reduce any difference between target and estimated profit and thus to achieve "allowable cost."

In the former case, a special project team called a "cost kaizen committee" is organized, and the team implements value engineering (VE) activities. The following distinction between VE and "value analysis" (VA) can be made: VE is the cost reduction activity that involves basic functional changes in the new product development stage, whereas VA is the cost reduction activity that involves design changes in existing products.[2] However, the distinction is not made in this case and the term "VE" is used. The establishment of a cost kaizen committee implies that the car model's kaizen has a top priority.

[2] Some companies distinguish VA from VE as described above.

The following is a real-life example of activities of the cost kaizen committee. Just after the oil crisis hit Japan in 1973, the profitability of one automobile model (Corolla) showed a marked decrease because of cost increases due to oil. At that time, the plant manager made the following proposals to the top management meeting concerning cost reduction:

1. Establishment of a cost kaizen committee chaired by the plant manager.
2. Promotion of a company-wide cost reduction program for the specific model.
3. As substructures to this committee, organization of the following three subcommittees:
   a. Production and assembly
   b. Design and engineering
   c. Purchasing
4. Establishment of a cost reduction goal of 10,000 yen (about $75) per automobile.
5. Expectation that the above goal would be achieved within six months.

Through a concerted effect by all departments based on the decisions of the cost kaizen committee, the actual result of the plan was 128 percent attainment of goal at the end of six months.

The second category of kaizen costing—reaching cost reduction targets established for every department as a result of the short-term profit plan—will be explained in the following sections.

§ 3 PREPARING THE BUDGET

The periodic cost-improvement process is preceded by the annual budgeting process, or short-term profit planning process, which represents the first-year segment of a three- or five-year long-range plan (see Figure 15.2). In the short-term profit planning process, each department prepares the following:

Plan 1. Production, Distribution, and Sales Plan (which includes projections of contribution margins from sales).
Plan 2. Projected Parts and Materials Costs.

	Budgeted Operating Profit
	Budgeted sales
From Plan 1	(Less) Expected variable costs (= standard costs)
	Estimated contribution margin
From Plans 2 and 3	(Plus) Target amount of reduction in variable costs
	Budgeted contribution margin
From Plans 4, 5, and 6	(Less) Budgeted fixed costs
	Budgeted operating profit

FIGURE 15.2
From sales forecast to budgeted operating profit.

Plan 3. Plant Rationalization Plan (projected reductions in manufacturing variable costs).
Plan 4. Personnel Plan (for direct labor workforce and service department personnel).
Plan 5. Facility Investment Plan (capital budget and depreciation).
Plan 6. Fixed Expense Plan (for prototype design costs, maintenance costs, advertising and sales promotion expenses, and general and administrative expenses).

These six projections and plans, when their costs and profits are incorporated together in the current period planning process, become the annual profit budget.

The production, distribution, and sales plans are the nucleus of the current period planning process. Plan 1 establishes the estimated contribution margin using a variable costing approach, based on the actual cost performance of the previous year, and the estimated volumes and prices of car models in the coming year, as shown in the following formula.

$$\text{Total estimated contribution margin} = \begin{array}{l}\text{the sum of contribution margin}\\ \text{per unit of each car model } i\\ \text{of the previous year}\end{array} \times \begin{array}{l}\text{estimated sales volume}\\ \text{of the car model } i\end{array}$$

The actual cost performance of the previous year is used as the cost standard for the coming year.

Projected parts and materials costs provide the targets for the purchasing department. The plant rationalization plan, which represents projections for reductions in manufacturing variable costs, is the core component of kaizen costing practice in a plant. It provides variable manufacturing cost reduction targets. The personnel plan provides cost reduction targets for direct and indirect labor.

The sales forecast for the year turns into budgeted operating profit through the following process, as illustrated in Figure 15.2. Expected variable costs, which represent standard costs, are subtracted from budgeted sales to yield estimated contribution margin in Plan 1. Plan 2 and Plan 3 provide budgeted changes in variable costs, which are used to adjust the contribution margin. Budgeted fixed costs from Plan 4, Plan 5, and Plan 6 are deducted from the budgeted contribution margin to produce budgeted operating profit. The labor costs of sales and administrative departments are treated as fixed costs because labor transfers within the company do not change the total labor cost used in the profit plan for the company as a whole; some of them are *managerial* capacity costs in each year. The cost improvement plans (Plan 3 and Plan 4) are integrated with the profit plan. Plan 2, Plan 5, and Plan 6 also influence costs.

Different methods are adopted because of the difference between variable and fixed costs. For example, variable costs such as direct materials, coating, energy, and direct labor costs are managed by setting the kaizen cost per unit for each product type. Fixed costs are subject to decisions of top management based on the overall amount of kaizen cost instead of the amount of kaizen cost per car.

Since the purchasing department supervises the purchase price of parts from outside suppliers, in the factory the most important subject is the use of VE activities to reduce the direct material costs. Usually, the purchasing department does not have a kaizen cost target for its own departmental expenses, but attempts to reduce the cost of parts by promoting VE proposals from vendors as well as by negotiating prices with vendors.

As for direct labor costs, monetary control as well as physical control in terms of labor hours is implemented by using the cost decrease amount as the kaizen cost target. A similar approach is applied to material costs improvement.

It is much easier for factory workers to understand the kaizen targets when cost *reduction* targets for variable costs are presented individually rather than as a total cost target.

§ 4 DETERMINATION OF THE TARGET AMOUNT OF COST REDUCTION

Japanese automobile companies determine the amount of profit improvement (i.e., kaizen profit) based on the difference between target profit (planned by a top-down approach) and estimated profit (computed as a bottom-up estimate). They usually intend to achieve half of that amount through sales increases and half through cost reduction. Of course when the industry is in recession or depression, greater weight will be imposed on cost reduction.

For generating cost savings, reductions of both variable costs and fixed costs are considered. As most manufacturing fixed costs are needed for maintaining continuous growth, Japanese automobile companies generally think that the kaizen cost in the plants should be achieved mainly by reducing variable costs, especially direct material and direct labor costs.

However, in non-manufacturing departments, the kaizen cost (or kaizen expense) reduction is set for fixed costs. Departments affected include the head office, research and development, and sales. The design department is usually not assigned a target amount of kaizen cost, and the purchasing department is not assigned one except in special cases such as an oil crisis, a currency appreciation, great depression, or similar circumstance.

To estimate the target cost reduction in the manufacturing division, the target cost reduction rate for each cost element is established beforehand, relating the cost base per car at each year-end to that the cost base for the following year, as shown in Figure 15.3. The company-wide target reduction amount is computed as follows:

Target reduction amount for all plants in the coming year
= $\Sigma_i \Sigma_j$ (planned production volume of product *i* this year)
× (per-vehicle standard cost for cost item *j*)
× (target cost reduction rate of cost item *j*)

This total target reduction amount will be proposed to top management by the accounting department, and top management makes the final decision as to whether this figure can satisfy the target company profit improvement.

The target kaizen cost assigned to the manufacturing division will be allocated to each plant based on the amount of *controllable costs*. The costs directly controlled by a plant include direct material costs, direct labor

Cost Elements	Evaluation Measures	Annual Target Reduction Ratio
Direct Materials Costs		
Raw material (Casting material sheet metals, etc.)	Monetary amount per unit of car	2%
Purchased parts	Monetary amount per unit of car	4%
Other direct materials (paints, thinner, etc.)	Monetary amount per unit of car	8%
Processing Costs		
Variable:		
Variable indirect materials (supplies, etc.)	Monetary amount per unit of car	8%
Parts transportation	Total monetary amount	10%
Variable overhead (utilities)	Monetary amount per unit of car	4%
Direct labor	Labor hours per unit of car	6%
Fixed:		
Indirect labor	Number of workers and overtime	Note 1
Other fixed costs:		
Office utilities	Total monetary amount	4%
Service department	Total monetary amount	*
Depreciation	Total monetary amount	*

* The target reduction rate is not established for these cost elements. The difference between the budgeted and actual total amounts is used to evaluate the rationalization (cost reduction) efforts. (The target reduction rates shown here are examples only.)

FIGURE 15.3
Target reduction rate for each cost element.

costs, variable overhead costs, and so on. Excluded are fixed costs such as depreciation. The kaizen cost for each plant is decomposed and assigned to each division, and in turn the division kaizen cost is assigned to smaller units of the organization. Some details about the method of assignment are considered in the next section.

The kaizen cost target is achieved by daily kaizen activities. The JIT production system also fosters the reduction of various wastes in the plant through daily activities. Therefore, kaizen costing and the JIT production system are closely related.

§ 5 KAIZEN COSTING THROUGH "MANAGEMENT BY OBJECTIVES"

Each manufacturing plant has objectives pertaining to efficiency, quality, cost, and so on. The concrete targets for physical objectives are determined and evaluated in the production meeting, while kaizen cost targets are determined and evaluated in the kaizen cost meeting.

The cost meetings are held at several organizational levels, for example, at the plant, division, department, section, and process levels. In the cost meeting for each level, the amount of kaizen cost—that is, the amount of the reduction target—is assigned through "management by objectives" at that organizational level.[3] That assignment is called "objectives decomposition" (or "objective deployment"), and it is implemented according to concrete purposes and policies determined in advance.

However, it is essential that the objectives decomposition be implemented not uniformly, but with consideration for individual cases. Moreover, the determination of each objective—the evaluation measures, countermeasures (remedial actions), and so on—must be implemented flexibly depending on each specific situation. The outline of objectives decomposition in the plant is shown in Figure 15.4.

Figure 15.5[4] shows an example of objectives decomposition for attaining the kaizen cost target in a machining department. Figure 15.6 is another example in a stamping department.

In Figure 15.4, managers at each organizational level determine policies and means to attain the kaizen cost target in their department. Their policies and means are mostly non-monetary measures, but the purpose is to realize the kaizen cost target.[5] Managers at each level try to reduce actual labor hours, whereas the accounting department computes the actual labor costs and overhead based on these actual hours. Then actual labor hours and actual labor costs at each organizational level are publicized each month and the result is reflected as incentive pay in employee salaries. This is a very strong incentive. Thus, both production management and accounting control are functioning at the same time in the company.

In floor-level control activities, the JIT production system has contributed to the reduction of costs remarkably. It is a system that reduces costs by thoroughly excluding waste in plants. Reducing inventories forces managers to clarify many problems in plants. As inventories are reduced,

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[3] For detailed characteristics of Japanese management by objectives, see Monden (1989c) in Monden and Sakurai (1989), pp. 413–423.

[4] In Japanese automobile companies each process shown in Figures 15.6 and 15.7 constitutes the "process" in the process costing system, and each process is headed by a foreman.

[5] The managers also have objectives of quality and productivity (efficiency or lead time reduction) as well as a kaizen cost target.

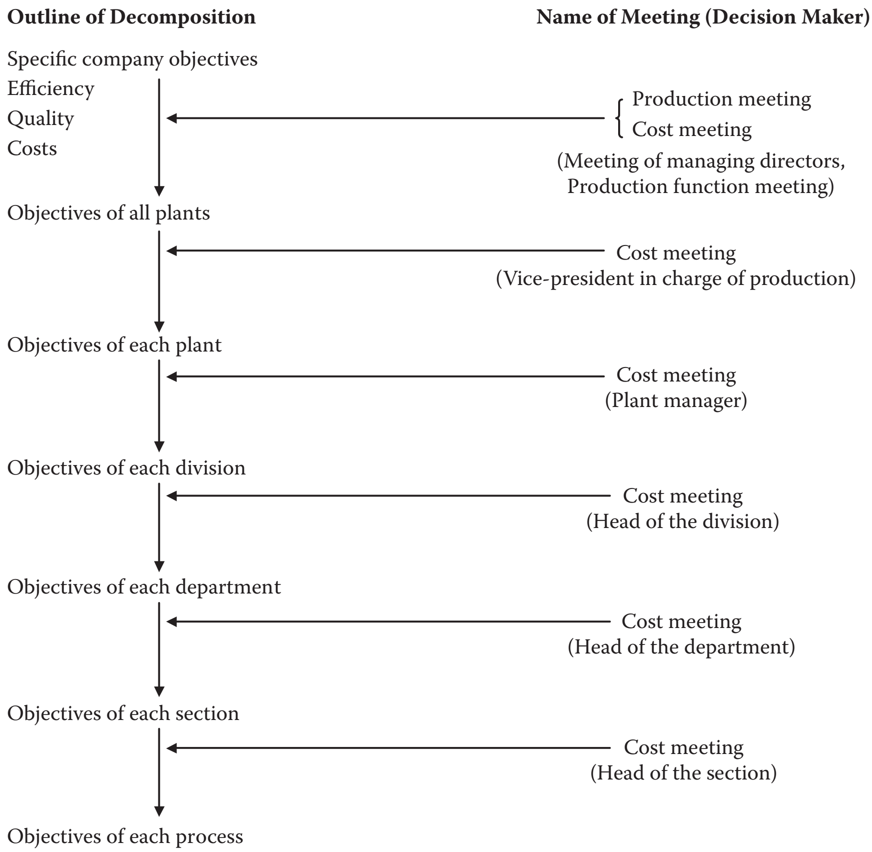


FIGURE 15.4
Objectives decomposition in plants.

the possibility of line-stoppages in problematic places increases. This in turn leads to cost reductions as causes of line-stops via defective units and machine breakdowns are investigated.

As indicated above, through the kaizen costing process, accounting control is used for assigning kaizen cost targets to plants, divisions, and departments, and production and quality control by non-monetary measures is used for floor-level control activities. On the manufacturing floor, everyone is involved daily in kaizen activities through QC circles and suggestion systems. Thus, in Japanese automobile companies accounting controls as well as floor-level controls are integral parts of the kaizen costing process.

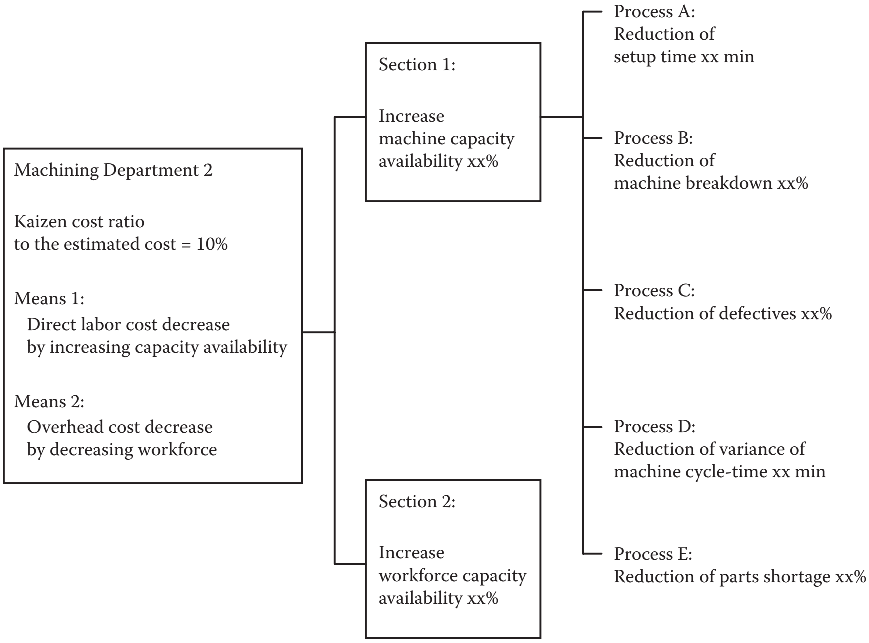


FIGURE 15.5
Kaizen cost decomposition in a machining department.

§ 6 MEASUREMENT AND ANALYSIS OF KAIZEN COSTING VARIANCES

Although some aspects of variance analysis for kaizen costing have not been fully developed, certain distinctions can be recognized during the evaluation of a department's performance results by analyzing volume variance, budget variance (or efficiency variance), and "spec variance" for design changes resulting from current-term VA (value analysis) activities (such spec variance is regarded as part of the budget variance).

This section examines the procedure for carrying out basic variance analysis for kaizen costing systems.

The following series of formulas can be used to measure each department's kaizen costing result for the prior month (also known as the "monthly rationalization amount"), which we then compare to the month's target reduction amount. The illustration in Figure 15.7 provides a visual aid for learning these formulas and steps:

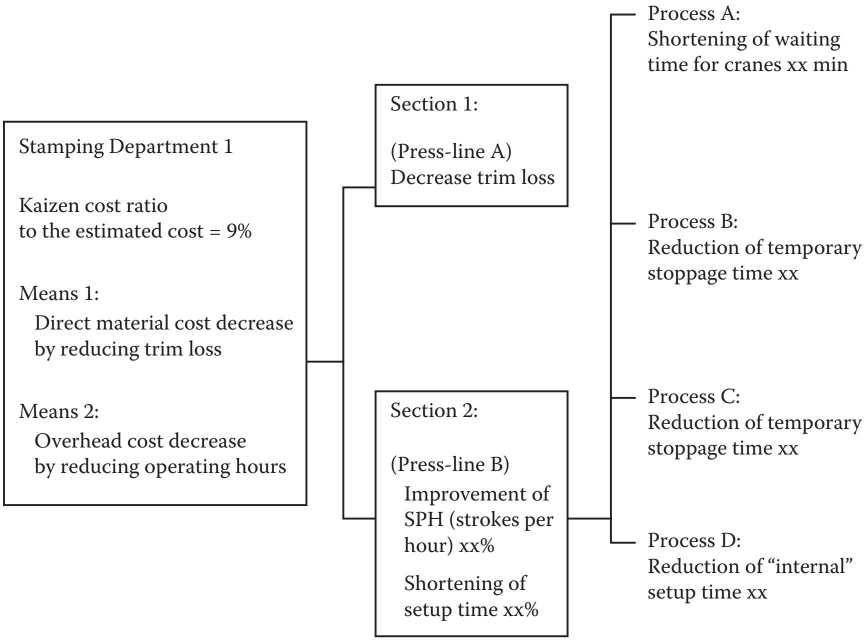


FIGURE 15.6
Kaizen cost decomposition in a stamping department.

(4) Current month's reference amount
= **A** Standard costs per vehicle unit
× (2) Current month's actual vehicle amount

(6) Current month's kaizen costing results
= (4) Current month's reference volume
– (5) Current month's actual costs (total)

(7) Current month's adjusted kaizen costing results
= (6) Current month's kaizen costing results
× {(Current month's referenced vehicle volume)
/ (current month's actual vehicle volume)},

Where the monthly reference volume
= (current month's kaizen costing results) / 12 months.

Kaizen costing variance = (7) Current month's adjusted kaizen costing results – Target reduction amount

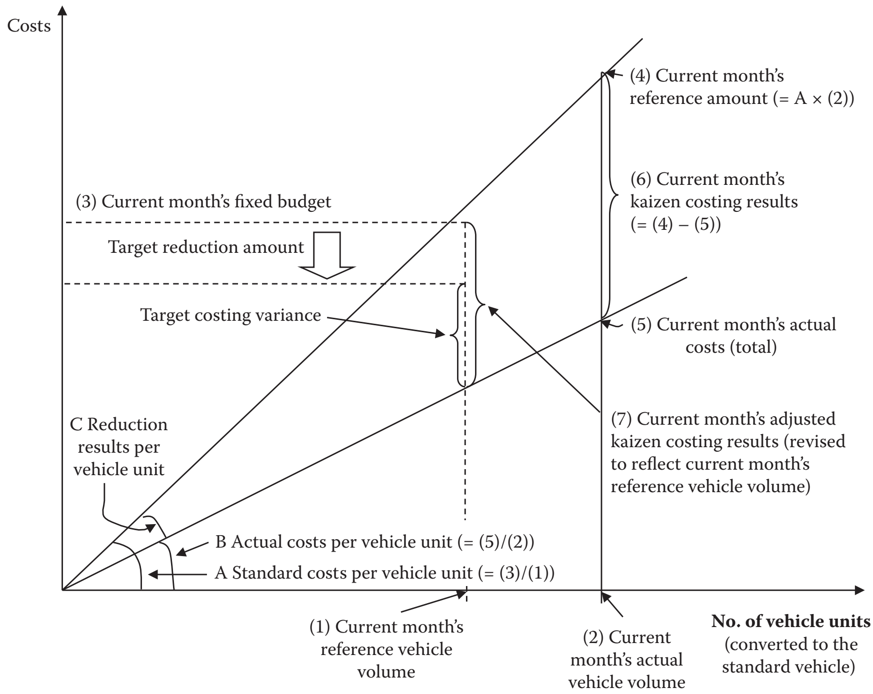


FIGURE 15.7
Calculation of monthly kaizen costing variances.

The results of these calculations are recorded in a monthly kaizen costing results table (such as the example shown in Figure 15.8), which is sent to management for review. The "current month's adjusted kaizen costing results" figure is derived from the current month's kaizen costing results by removing the volume variance.

The following is a simple method for calculating the current month's adjusted results:

> **B** Actual cost per vehicle unit = (5) / (2)
> **C** Reduction results per vehicle unit = **A** – **B**.
> (7) Current month's adjusted kaizen costing results
> = **C** Reduction results per vehicle unit
> × (1) Current month's reference vehicle volume

The variance calculated here is the real performance indicator for a specific department. It indicates whether an actual cost reduction that has been achieved is satisfactory compared to the target. Even an actually

	Current Month			Cumulative		
	Target	**Actual**	**Variance**	**Target**	**Actual**	**Variance**
Plant A Costs						
Direct labor	40	35	(5)	160	165	5
Indirect labor	0	(5)	(5)	0	(35)	(35)
Material	15	25	10	60	75	15
Energy	10	15	5	40	50	10
Transportation	5	5	0	20	35	15
Total	70	75	5	280	290	10
Plant B Costs						
Direct labor	20	25	5	80	75	(5)
Indirect labor	0	5	5	0	10	10
Material	10	5	(5)	40	25	(15)
Energy	5	0	(5)	20	15	(5)
Transportation	5	2	(3)	20	15	(5)
Total	40	37	(3)	160	140	(20)

Note: Target: Target cost reduction amount; Actual: Actually realized amount; (##): Loss or unattained amount

FIGURE 15.8
Kaizen costing performance evaluation.

rationalized amount that is positive is evaluated as "unfavorable" if the variance from the target is negative (see Figure 15.8).

In Figure 15.8, Plant A as a whole has exceeded the kaizen target by +5 although the actually rationalized amount of indirect labor cost was –5. Plant B, with an unfavorable variance of 3, has not attained the kaizen cost target.

16

Material Handling in an Assembly Plant

§ 1 THE PARTS SUPPLY SYSTEM IN AN ASSEMBLY PLANT

The number of parts that had to be supplied to the final assembly line in a certain mixed-model automobile production plant was huge. However, there was not much room beside the line, so it was difficult to keep stocks of a great variety of parts there in large quantities. Also, the operators had to select the part they needed for each vehicle from a wide array of parts racks, which placed a heavy burden on them.

The question of how to move the parts efficiently onto the line was therefore a pressing topic. Its solution also gives us a hint as to how to supply a large variety of parts to the sides of the cells in a cell production system.

§ 2 A SYSTEM FOR SUPPLYING PARTS IN SETS (THE SPS, OR SET PARTS SYSTEM)

The SPS System

The SPS (Set Parts System), a system for supplying parts to a production line in sets, has recently been adopted for the final assembly line at Toyota's Tsutsumi Factory in Japan (Noguchi, 2005). This system consists of the following (see Figure 16.1):

Step 1: Sets of all the parts needed for each vehicle are prepared in advance in the SPS area (a special area dedicated to picking parts in sets) on the upper level of the assembly shop, and are placed in "set boxes." These set boxes are in turn placed on wagons that move along with the flow of the assembly line vehicle conveyor on

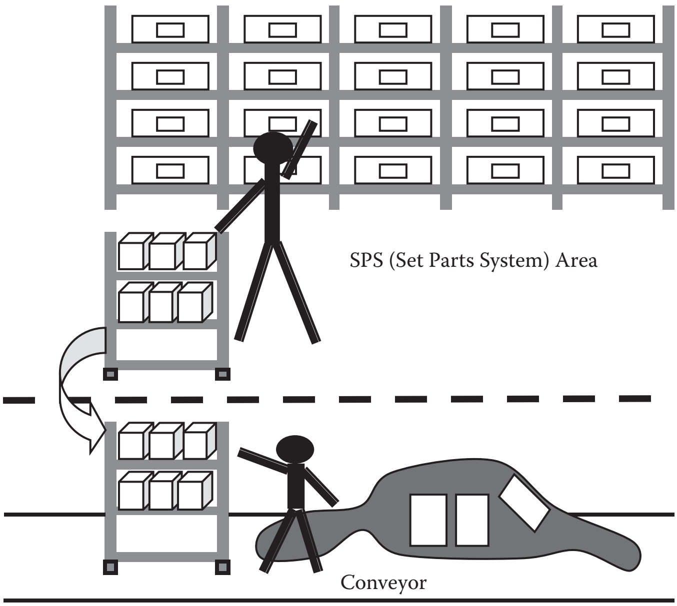


FIGURE 16.1
Set Parts System (SPS).

the lower level. In the SPS area, picking operators select the parts accepted from the suppliers, following instructions given by indicator lights.

Step 2: The assembly operators then take the parts one after another from the set box with the relevant job number on it, and install them on the appropriate vehicle.

As a result of introducing this system, the lineside parts racks (flow racks) were eliminated. The AGVs (automated guided vehicles) that used to travel around supplying parts to the racks were also made redundant.

Approximately 350 parts have to be supplied to the lineside for one vehicle, and these are now supplied in the form of 10 sets (or 10 boxes). However, what is meant by "the parts required for one vehicle" here is that the various parts used *at each workstation on the conveyor* are placed in set boxes, which are then collected on the wagon and supplied to the line. (At the "vehicle assembly docks" [a type of cell] used at one time at Volvo's factory in Sweden, the parts for an entire vehicle [not just for a conveyor workstation] were split into about four groups and were supplied to the line on "parts kit trolleys." The SPS system is similar to this in some respects, but the differences between the two should be clearly recognized.)

The Rationale for SPS, and Its Benefits

Vehicle assembly at the Tsutsumi Factory was originally done on two floors, and the two assembly lines (installed at the same time) were then producing up to 8 different models simultaneously in a mixed-model flow.

Six models (Premio, Aurion, Caldina, Opa, Wish, and Scion) were being produced on the No. 1. Line, and four (Premio, Aurion, Camry, and Prius) on the No. 2 Line. These different models also came in various body types (sedan, wagon, minivan, etc.).

With mixed-model production of such a large number of different vehicle types, streamlining the main lines (that is, synchronizing the workstations, or balancing the lines) was essential. In doing so, the Toyota engineers were able to halve the width and length of the original main lines, by actions such as taking unit parts that disrupted the flow of the main lines off these lines and assembling them on sub-lines.

However, just as at Toyota's Miyahara Factory in Kyushu in the 1990s (see Chapter 28), Line No. 1 and Line No. 2 at the Tsutsumi Factory were each composed of ten mini-lines. For example, the Prius hybrid car was being assembled on the No. 2 Line at the Tsutsumi Factory. This meant that both gasoline cars and hybrid cars were being assembled on the same line. However, the Prius took longer to assemble because of its unique construction. To allow for this, unit parts for the Prius were assembled on a sub-line (a dedicated process line) and sent to the main line, in order to absorb as far as possible the extra labor required compared to gas-driven cars. On the main line, the assembly labor was smoothed out as much as possible.

As a result, a great deal of space was freed on the upper floor, making it possible to set up an SPS area. The sequenced supply of parts to the final assembly lines by means of e-kanban (electronic kanban), which were applied to all outsourced parts, may also have helped to free up space.

Next, the reasons for introducing SPS, and the benefits obtained, will be described.

Reason 1: The Number of Different Models Being Passed Down the Same Assembly Line Had Increased

The Tsutsumi Factory was producing 8 different models, and this increase in number meant that the shop floor was being overwhelmed with the work involved in switching from one model to another, creating large changeover losses. More and more work was also required to prepare for the production of other models.

The assembly operators' memories were being overloaded by having to work out which parts to pick from the parts racks each time a different model came down the line. There is a limit to the number of different models for which an assembly worker can complete both the selection and installation of parts within the takt time. Overtaxing the assembly workers may also adversely affect the stability of product quality.

Reason 2: The Average Age of the Shop-Floor Workers Had Increased

The average age of factory workers is increasing in many countries, and particularly in Japan. When this happens, measures must be introduced to ensure that they do not become overstrained. Another reason for introducing SPS was therefore to alleviate the physical workload on older workers, by having the "veterans" select the parts and the younger workers install them. This actually lightened the burden on both younger and older workers.

Reason 3: In Overseas Factories, It Is Necessary to Create Simple, Slim Assembly Work Systems That Allow the Local Employees to Do the Job Easily

Having operators both select and install parts is asking them to do a very complicated job. Splitting up the two tasks and giving them to different people makes the assembly task much easier. Even if many different models have to be assembled, it is much simpler to learn the job.

Also, it becomes much easier for line leaders and supervisors to see the work being done in each process on the conveyor when a line is simple and slim, so they can control the line more easily. At the Tsutsumi Factory, each assembly operator used to have one parts rack, but, after introducing SPS, this went down to one rack shared between two operators, and the racks became shorter and simpler as well.

The Greatest Benefit

The greatest benefit of satisfying the three requirements described above by means of SPS was that the assembly workers were now able to devote themselves to building quality into the product, and the quality therefore improved greatly.

§ 3 "EMPTY-HANDED" TRANSPORTATION

Rationalizing the Reception of Outsourced Parts and the Removal of Empty Boxes

The so-called "unit parts" (large parts such as engines, transmissions, and seats) always used to be supplied to the final assembly line in the same sequence as that in which the vehicle models for which they were needed came onto the line. However, the introduction of e-kanban made it possible to do this not just for unit parts but for all the parts brought onto the final assembly line. This meant that stocks of outsourced parts in the factory's goods-in area and at the lineside could be reduced dramatically, freeing a great deal of space in those areas.

This extra space was used effectively to arrange the reception of incoming parts efficiently and improve the way in which the empty pallets were stored inside the assembly shop. To accomplish the first of these purposes, a coupling station was set up for the trolleys used to bring the parts in to each assembly line. For the second purpose, an area for storing each parts manufacturer's empty pallets was set up. An explanation of how these are used is provided below (see Aoki, 2007, pp. 78–82) and in Figure 16.2.

Movement of the Site Materials Handler

Area for Storing Each Parts Manufacturer's Empty Pallets, and Trolleys with Tractor

Since the introduction of e-kanban had freed up space in the goods reception area, a new area for storing each parts manufacturer's empty pallets was set up, where empty boxes were collected after the parts had been used on the assembly line.

Step 1: After the parts have been brought in by the truck drivers, the site materials handler takes them from the outsourced parts placement area and piles the parts boxes with parts in them (loaded pallets) onto trolleys that have also been retrieved from their storage area. A trolley is a pedestal or base onto which the parts boxes are placed. The trolleys are then pulled by a tractor to flow racks, or parts racks,

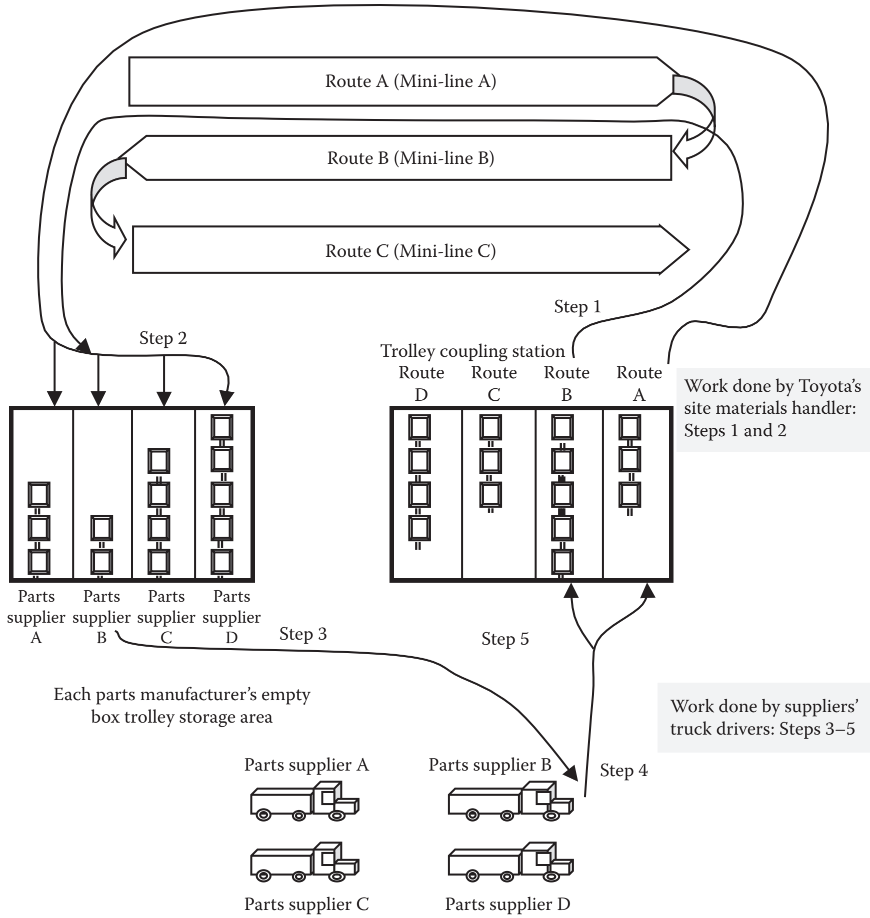


FIGURE 16.2
"Empty-handed" transportation. (Adapted from Aoki, M., 2007, p. 79, with revision.)

close to the assembly line. (However, there are not many of these flow racks next to the line these days because of SPS system explained in § 1, although the parts used to be supplied directly to the line.)

Step 2: At the same time, the site materials handler recovers the empty parts boxes (empty pallets) and arranges them on the trolleys. He or she then drives them to the empty pallet storage area in the parts reception area, where each parts manufacturer's empty pallets are stored separately. Each supplier's trolleys are connected together to form a train for that particular supplier.

Movement of the Parts Manufacturers' Drivers: Coupling Station for the Trolleys Used to Bring the Parts in to Each of the Assembly Lines

When a parts manufacturer's driver arrives at Toyota's parts reception area, he or she (let's assume it's a "he") performs the following actions (see Figure 16.2):

Step 3: He first gets on a tractor and drives it to his company's empty pallet storage area. He then uses the tractor to pull the train of trolleys with his company's empty boxes piled on them back to his truck.

Step 4: He then uses a forklift to take trolleys with full boxes on them off his truck and swap these for the trolleys with empty boxes on them.

Step 5: He then drives the train of trolleys with full boxes on them to the coupling station for the trolleys used to bring the parts in to each of the assembly lines (or routes). He separates the trolleys into those for each assembly line or route and connects them to any trolleys already there. The e-kanban tells him which route he should assign to each trolley; it shows the name of the route and the address of the placement location.

17

Further Practical Study of the Kanban System

This chapter will attempt to explain the many miscellaneous practices of the kanban system. The Toyota kanban system is used to control processes so that every process will produce a single unit of product within a predetermined cycle time. Therefore, the ability to produce a *one-piece conveyance* (called "Ikko-Nagashi" in Japanese) is viewed as the ideal state of this system. From this fundamental viewpoint, the production of large lot sizes and the holding of large inventories between processes are redundant. In such a situation, the number of kanban required is also increased.

Although one-piece conveyance is the ideal state of this system, many processes have great difficulty in achieving such a goal. An example of this occurs in the pressing process of automobile manufacturing. In such lot production processes, even though a *triangular kanban* or *signal kanban* is used, a continuous improvement effort must be made to ensure that the lot size is minimized.

§ 1 MAXIMUM NUMBER OF PRODUCTION KANBAN TO BE STORED

If the final assembly line stops frequently because of various problems and production is often delayed, parts withdrawal will be made according to a *constant-quantity and inconstant-cycle system*. Also, if production in a subsequent process is not necessarily smoothed, and the preceding process is producing in small lots, then how will the production order be made?

The function of a production-ordering kanban on a gear-grinding line for small trucks will be examined in this section. At the starting point of this machining line, the production kanban posts are equipped for every part to be processed. White, green, and yellow papers are pasted on the frames of this kanban post for each part. This makes it possible to see how many stocked kanban are in this kanban post at the beginning of the process. When the kanban are stocked in the white or green frames, production of these parts need not be started yet; but the moment the kanban is put into a yellow frame, production should begin. Consequently, the total number of kanban stocked up to the yellow frame is directly equivalent to the number of kanban in the lot size plus safety inventory. An example of the production kanban post in Daihatsu's plant is shown in Figure 17.1.

In this case the maximum carrying number of production kanban is the order quantity for each part in question, and this maximum number is also equivalent to the parts usage quantity of the subsequent process during the lead time of the production kanban. The *lead time of the production-ordering kanban* is defined as the interval between the time when the *production-ordering kanban* were detached at the *completed parts storage* of the process in question, initiating the production of the number of parts corresponding to this detached number of kanban, to the time when the same process can replenish these produced parts to their completed parts storage as stock.

Chapter 22 covers the *two-bin system*, whose concept will be applied here. In the two-bin system, the bin implies a large box; two boxes of inventory are produced as a starting point. When one box of inventory goes out of stock, the inventory of the other box will be used, and the empty box will trigger an order for one box of parts to be replenished.

Now, suppose we reduce the capacity of each box to half and we increase the number of boxes of inventory in the subsequent process to four. In this case, two boxes will correspond to the two sheets of production kanban to be kept as maximum in the production kanban post of the preceding process.

In general, an acceptable number of kanban stocked in the *production-ordering post* is determined by the daily average figure derived from the monthly production quantity. Although this number generally depends on the turnover time, it usually ranges from one to three kanban.

The progress made on each process can be detected by the kanban system. For example, if the kanban are not smoothly stocked on time at a *production-ordering post*, production is delayed in a subsequent process. Vice versa, if kanban are stocked earlier than scheduled, the subsequent process is proceeding too fast. Just by looking at the *production kanban post*, operators can visually understand the rate of production at a subsequent process.

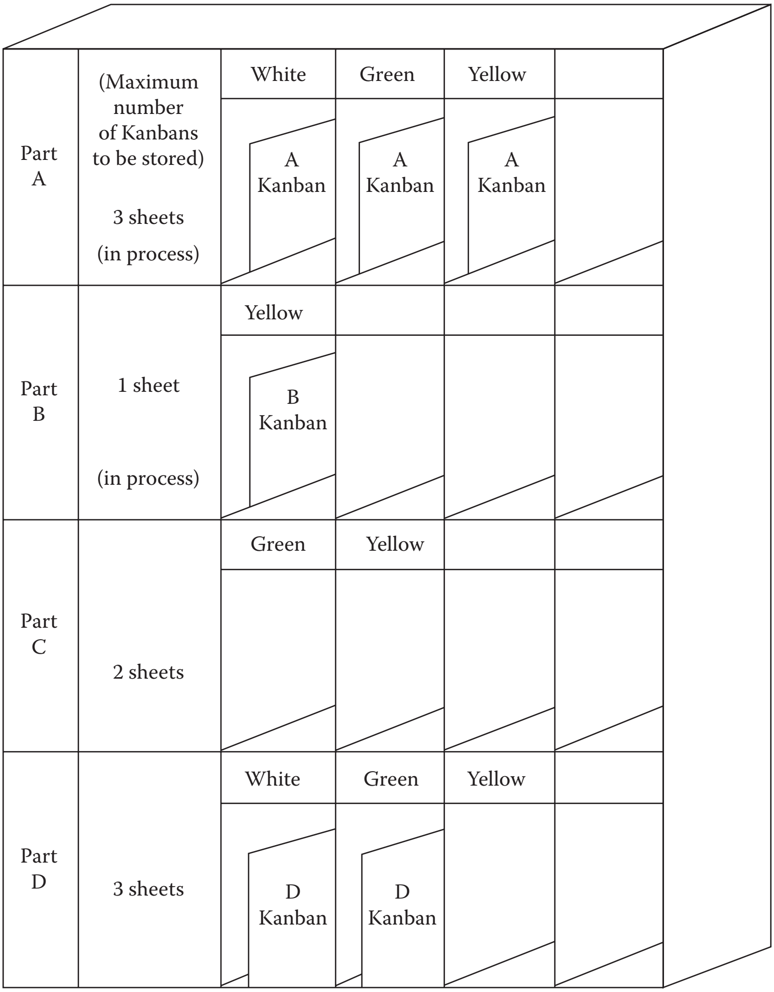


FIGURE 17.1
Production-ordering kanban post.

One of the merits of the kanban system is that it enables observation of the workplace at short intervals of time and is thus able to realize frequent improvements. For example, if products are conveyed in one-hour intervals by the kanban system, control of the proceedings in one-hour intervals is possible; if products are transported every ten minutes, the proceedings can be controlled every ten minutes. In the latter case, since the process speed is checked every ten minutes, its activities will be made clearer and machining or assembling speed can be checked.

By adopting a system in which the preceding process produces the same quantity of parts as is withdrawn by the subsequent process, waste (in this case overproduction) becomes clearly visible. For example, operator waiting time at a conveyor line becomes obvious by comparing actual cycle time with the required takt time. In lines that do not contain conveyors, if conveyance from a subsequent process is made at ten-minute intervals and if the activities of the preceding process are observed at the same ten-minute interval, the amount of waiting time experienced by the preceding process will also become visible. If the waiting time is transformed into actual physical products, the existence of this idle time will be masked. But, as long as the kanban system's principles are followed, the masking of idle time by its conversion into physical products will be avoided.

For accounting and monthly maintenance of the number of kanban used, Toyota has implemented computer and bar code technology. However, in-process kanban are not bar coded because a monthly payment is not required for the units to be conveyed within Toyota's plant. Also, grasp of the actual production quantity by bar coding is unnecessary as it is already monitored by *production control boards* (a type of andon), hourly for every process. In assembly lines, et cetera, assembling is designated by the issue of magnetic card instructions or IC cards, while actual control of the proceedings is maintained by the reading of these ID cards at the end of several processes. Activity control in processes other than these is maintained by kanban.

§ 2 TRIANGULAR KANBAN AND MATERIAL REQUISITION KANBAN ON A PRESS LINE

Next, the structure of a press plant will be examined to understand how a kanban circulates there. Basically, in a press plant there are two kinds of lines: a cutting line for coils and a press line. The purchased coils are stocked in a storage area located just before a coil-cutting line. Another storage area (called a sheet-store) containing the cut coil (steel-sheets) is situated after the coil-cutting line. Ideally, the quantity of stocked coil should be just enough for one-shift's use; however, there are times when a roll of coil is too big to be finished in one shift. In this case, the same roll is used in two or three shifts. In addition, enough inventory for one-shift is also kept at the storage area for the cut steel sheet. Several press lines exist. Behind each is a storage area for processed sheet metal where various pressed parts are placed in pallets. A triangular kanban and a material requisition kanban are hung from these pallets.

When the pallets have been used down to the material requisition kanban, the kanban is removed. Similarly, when pallets have been used down to the point of a triangular kanban (reorder point), it is also detached. The triangular kanban will be hung on a kanban post (or a kanban hangar) on the way to the press line. Triangular kanban are then collected from the kanban post two times a day—at precisely 9 a.m. and 4 p.m.—and hung on a production-ordering post (called a stamping-order control board) at the start of the press line. The production-ordering post is used to signal the start for the pressing process at the press line.

Triangular kanban are not carried directly to the production-ordering post from pallet storage because a press line is very long and it is more efficient to let these pile up and be transferred in groups. Triangular kanban are first stocked in the kanban hangar and conveyed together to the production-ordering post twice daily. Figure 17.2 shows how material requisitions and triangular kanban circulate within the press plant.

The Roulette System

A roulette is used for processing press parts that have relatively small consumption quantities. These are parts that have usage quantities smaller than the pallet size. Ideally, the pallet size should be reduced and the amount contained per pallet should be decreased. However, if the pallet size is not reduced, the roulette is utilized. The instructions for the use of a roulette appear in Figure 17.3.

For example, suppose a pallet contains 60 pieces of a particular part and the actual consumption of the part per shift is only ten. This means that enough parts for 6 shifts are being stored on one pallet. Thus, the necessary quantity for one shift is only one-sixth of the entire pallet. This can be expressed as

$$\text{standard pallet quantity} = 1/6 = 0.17$$

Rounding off 0.17 to 0.2, the standard pallet quantity comes to one-fifth of the box. Therefore a triangular kanban is put in area five of the roulette. For this type of part, production should not be started immediately even when the triangular kanban is put in its hangar because the parts stored in the pallet are enough for five shifts.

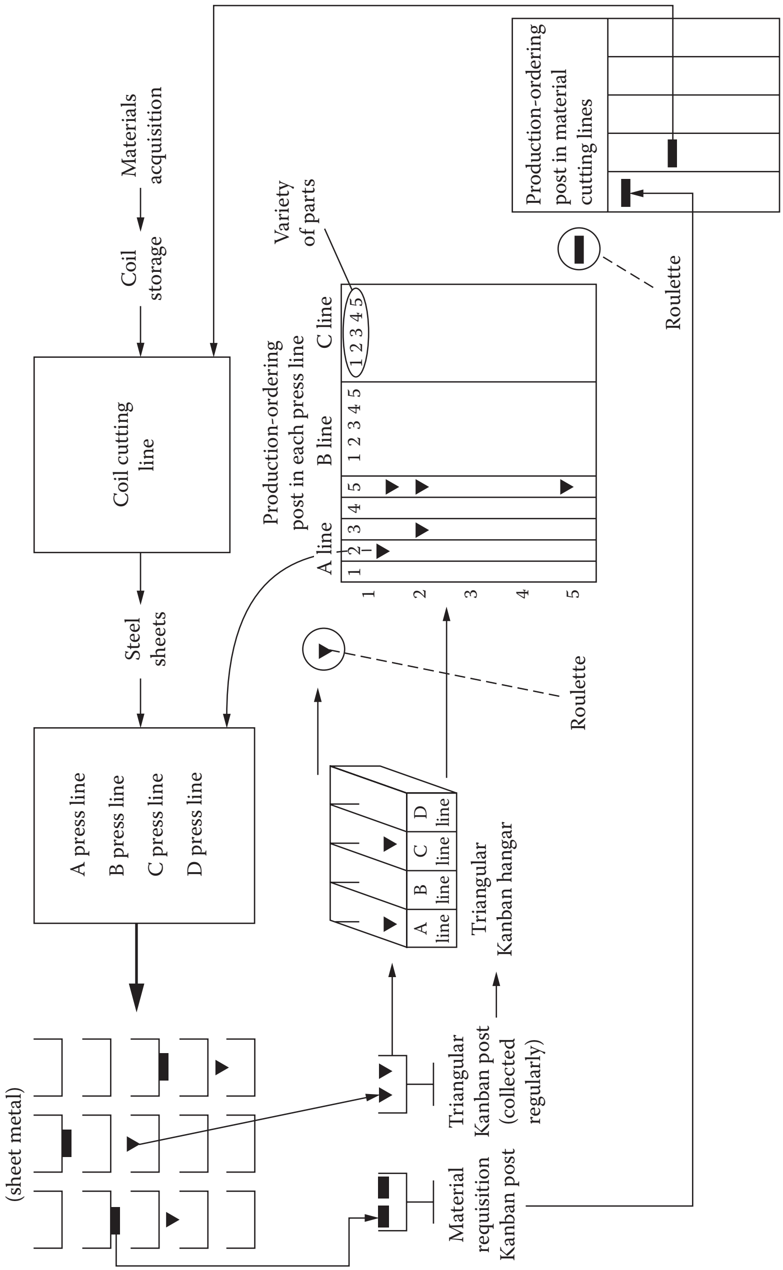


FIGURE 17.2
How to circulate the kanban in a press plant.

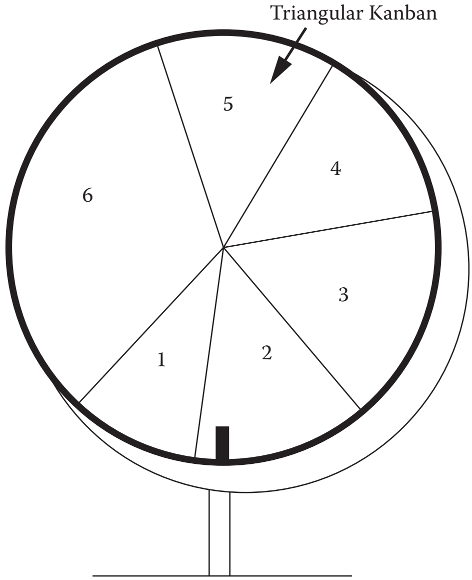


FIGURE 17.3
Roulette. (The roulette is rotated clockwise one block for each shift. In this example, when block 5 gets to the place now occupied by block 2, a triangular kanban is put into the production ordering post.)

§ 3 CONTROL OF TOOLS AND JIGS THROUGH THE KANBAN SYSTEM

Machining tools, such as various cutting bits or drills, have to be replaced regularly because of constant use. The specific quantity of parts that can be manufactured before the tools have to be replaced can be determined and planned in advance.

To control tool replenishment using the kanban system, toolboxes containing replenishment tools for every type of tool are kept beside the machining line. Every morning, a tool setter in charge of checking the tools replenishes the boxes with new tools. A daily record is kept of the number of tools that have been consumed and replenished. A tool-order kanban (a type of triangular kanban) is also used to order the tools needed.

According to Figure 17.4, a tool with item code T-3905 is to be ordered when six pieces remain according to the tool ledger. Tool-order kanban have magnetic strips on the back, which can be read by a card reader

Tool-order Kanban	
Item name code	T-3905
Reorder point	6 units
Lot-size (order-quantity)	10 units

FIGURE 17.4
Tool-order kanban.

and electronically transmit the required order quantities to suppliers instantly.

The reorder point is examined monthly by reviewing consumption quantities over the previous two-month period. Reorder points are revised as warranted.

§ 4 JIT DELIVERY SYSTEM CAN EASE TRAFFIC CONGESTION AND THE LABOR SHORTAGE[1]

JIT Will Contribute to Rationalization of Physical Distribution

In recent years, there has been growing criticism of the just-in-time (JIT), known as the kanban system, accusing it of being the ultimate cause of physical distribution problems. It is argued that JIT has caused (1) increased physical distribution costs (transportation costs), (2) a shortage of drivers, (3) traffic congestion, and (4) exhaust gases that pollute the environment.

No doubt, when the JIT system is examined in terms of individual parts, it is in essence a system involving the transporting of small lots—small volumes—of goods on each trip, and frequent deliveries carrying the average volume of goods each time. But it is illogical to say that this distribution system is the ultimate cause of the problems listed above.

For example, a glass manufacturer that delivers automobile glass to automakers in accordance with the kanban system is expected to deliver glass to the factory 20 times every day. If that total volume of glass is considered to equal 40 truckloads, and all the deliveries are done once in the morning, 40 trucks must leave at the same time every morning.

[1] Reprinted with permission of Nikkei. Originally published in the Japanese language in Nihon Keizai Shibun, August 7, 1991.

If every parts maker delivered parts in such large lots, the roads leading to the automaker's factory would be terribly congested. Forty truck drivers would be required at the same time, further aggravating the labor shortage. And because drivers would be on stand-by except when they were actually driving, this method would, in terms of society as a whole, constitute a terrible waste of human resources.

Now let us consider the small lot frequent delivery system. To begin with, because transportation costs are charged based on a contract which states that "payment of a certain amount is made for each shipment by each truck on each route," physical distribution costs remain the same whether 40 trucks are dispatched simultaneously or whether two trucks are dispatched together at 20 different times.

The multiple delivery approach means that each driver is involved in many trips each day, so that the turn-around rate per person increases, alleviating the labor shortage. Also, frequent deliveries of standardized small lots relieve traffic congestion the same way as a staggered work hour system. The same volume of exhaust gas is emitted by 40 trucks dispatched at the same time as by two trucks dispatched 20 times. If traffic congestion is avoided through small lot deliveries, specific products are delivered more quickly than they are when delivered in large lots, and the volume of physical distribution in a single day can be increased.

The ideals of the JIT system are satisfied if the physical distribution volume required in a single month is ordered during the month based on equalized daily requirements, not ordered during a designated week or on a designated day each month. This also serves to alleviate the labor shortage and traffic congestion.

Genuine JIT System Has Prerequisite Conditions

What then is the correct JIT physical distribution? The system in use at Toyota was basically developed as a JIT production control system (Toyota Production System). Therefore, the application of their system's concepts to the physical distribution for establishing a real JIT delivery system will be considered here.

The first condition is smoothing (leveling). At Toyota, smoothed production means calculating the approximate average daily sales volume for each month based on anticipated monthly sales, and producing (with the greatest possible accuracy) the average daily sales volume every day throughout the month. Accordingly, parts makers are to deliver almost the small average volume of parts each day. This smoothing concept is achieved by having frequent small lot deliveries even during each day. But "just in service," a term used by large volume retailers, cannot mean to provide consumers with equalized sales even though retailers ask wholesalers and part makers to provide a frequent small-volume delivery service. It is therefore difficult to equalize physical distribution in obtaining supplies.

The second condition is that it must not be non-stock production. On the average, inventories are maintained at half the volume indicated by the number of kanban cards, which is revised monthly. (One kanban card is the equivalent of one container of parts.) Leveled physical distribution at Toyota is possible because its dealers retain buffer inventories.

The third condition is that trucks must always be fully loaded. Trucks used to deliver parts must always achieve 100 percent loading efficiency. If this condition is not met—if each truck carries a different volume and partially empty trucks are frequently dispatched to deliver small lots—the systems cannot properly be called JIT physical distribution. It is far different from real JIT physical distribution; it is nothing more than high-handedness on the part of the party ordering the goods.

Certainly at Toyota too, the necessary quantity of each part item is getting smaller because of the tendency of an increased variety of cars with each small quantity. But, using the mixed loading method of various small lot items, Toyota has achieved full loading efficiency for each truck. From such an efficient mixed loading method, they developed their own standardized polyethylene containers of various sizes.

The final condition is that there must be leeway in the scheduled times that trucks arrive at their destinations. What happens if truckers are ordered to arrive according to a designated schedule that does not allow them any flexibility? Trucking company managers dispatch their trucks early so that they will not arrive at their destinations late, which forces truckers to wait on the highway to use up their excess time, or to drive aimlessly around their destination killing time until they can complete their deliveries.

External Environment for Physical Distribution Should Be Rationalized

Criticism of JIT physical distribution occurs because of confusion surrounding the meaning of JIT physical distribution. Converting incorrect or fake JIT distribution methods into genuine JIT distribution will help to alleviate some of the problem.

There are other factors besides the proliferation of fake JIT physical distribution systems behind the problems which have plagued physical distribution in recent years. Many are primarily the results of an increase in the overall volume of goods handled by the system (the weight multiplied by the distance) which has accompanied the expansion of the Japanese economy, and the increasing demand for convenience among Japanese consumers. The expansion of social capital in the form of a road network able to satisfy the increased scale of physical distribution has also lagged behind. It is necessary to increasingly build up the nation's road stock by improving intersections and by building loop expressways and bypasses. Other measures that would help include the completion of highway traffic information systems and traffic control systems.

It is also vital that the external environment surrounding physical distribution be rationalized by, for example, promoting a reduction in the number of different products transported, establishing joint delivery systems among parts makers, and establishing joint delivery centers so that the convenience store industry and manufacturers can deliver goods to each of their stores.

18

Smoothing Kanban Collection

§ 1 OBSTACLES TO COLLECTING SMOOTHED NUMBERS OF KANBAN

Unless a system for collecting smoothed (consistent) numbers of kanban is implemented at the front line of the plant, parts manufacturers may be inconvenienced. Although production may be smoothed at the final assembly line (in other words, the use of various kinds of parts is averaged or smoothed in the sequence schedule of the mixed-model assembly line), in reality, kanban might not be given in equal numbers to the parts manufacturers when the latter receive their kanban cards.

Following are the causes of this situation:

1. Because of a lack of synchronization between the timing of collecting kanban at Toyota's production site and the schedule of supplied parts delivery, in some cases the number of kanban that the parts manufacturers take with them may fluctuate.
2. Even if the above problem is solved, there are some cases in which kanban may not be collected at Toyota's production site at the designated time due to the collectors' own reasons, and thus collecting of kanban may be delayed.
3. Parts may be delivered to Toyota from the supplier later or earlier than the expected time due to transportation problems (e.g., traffic jams) and the number of kanban that the parts manufacturers take with them may therefore fluctuate.

The following sections explain how to solve these three problems.

§ 2 RELATIONSHIP BETWEEN SMOOTHED COLLECTION OF KANBAN AND PARTS DELIVERY

Toyota sets a rule that when operators on the assembly line or parts machining line take the first part from a parts pallet (parts box) on the lineside first thing in the morning, they remove the supplier kanban attached to the parts pallet and put them into the designated kanban post on their lines.

The person who is responsible for parts handling at Toyota goes to these kanban posts in the floor at each designated time and collects the supplier kanban. Collected supplier kanban are sorted into parts manufacturers' kanban mailboxes by a "supplier kanban sorter" located at the parts delivery window. Using the most recent delivery truck, the parts manufacturer's driver picks up the kanban in the mailbox to take them to his company.

In this system of delivering parts to Toyota from the parts manufacturers, unless there is any major line stoppage at Toyota, there should be no major change in the *number* of delivered parts (in other words, the number of supplier kanban) despite any changes in the *kinds* of parts, because automobile production is implemented at a set conveyer speed.

However, because of a lack of synchronization between the timing of collecting the kanban and the scheduled parts delivery, in some cases, the number of kanban that the parts manufacturers may take with them might fluctuate. Figure 18.1 shows a typical example.

Figure 18.1 depicts a case in which there are 10 kanban collections a day at the Toyota factory, while the parts manufacturer delivers parts only four times.

The first delivery truck to Toyota from the supplier picks up the supplier kanban from the first and second collections on that day, and from the

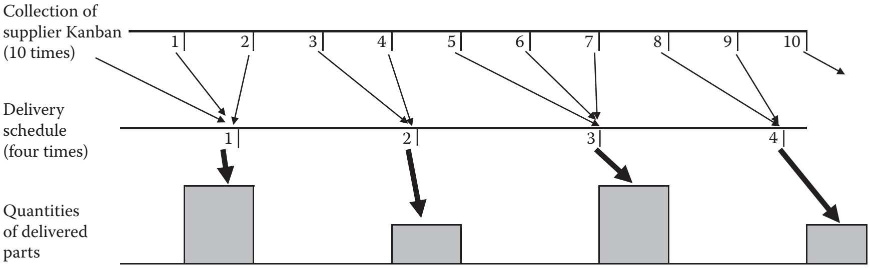


FIGURE 18.1
Frequency of collecting kanban can smooth delivered quantities of parts.

tenth collection on the previous day. The second delivery truck picks up the supplier kanban from the third and fourth collections on that day. The third delivery truck picks up the supplier kanban from the fifth, sixth, and seventh collections.

As a result, although Toyota implements smoothed production on their production line, the number of parts delivered by this method varies widely (up to as much as 50%). Consequently, it cannot be said that the parts manufacturers have achieved a smoothed delivery. Therefore, the parts manufacturers must prepare stock equal to the largest number of kanban at the peak time in order to make just-in-time delivery. Moreover, when the delivery truck carries only a light load, the truck has empty space.

Toyota has improved this situation by changing the frequency of collecting kanban to multiples of four. In other words, Toyota's kanban collectors collect kanban at a frequency of 4, 8, 12, 16, 20, or 24 times daily. On the other hand, different parts manufacturers deliver parts at different frequencies, but normally, they deliver with frequencies that are multiples of two, such as 2, 4, 6, 8, 10, or 12 times daily (that is, an even number). Consequently, Toyota adopts the lowest common multiple of both sides: 24 times per day.

Parts manufacturers that make 10 deliveries daily cannot smooth their delivery quantities. In this case, when collected supplier kanban are sorted by an "outgoing kanban sorter" located at the parts delivery window into the parts manufacturers' kanban mailboxes, Toyota will not put all the kanban in the mailboxes for these suppliers but, in order to smooth, will hold back some kanban cards for another interval. This practice is called "spreading for smoothed delivery."

As a result of all these efforts, the degree of fluctuation of the number of kanban has been reduced to within the range of "planned amount of parts ±10%," the limit of "fine tuned production by kanban."[1]

§ 3 SMOOTHING SCHEDULE FOR THE TIMING OF KANBAN COLLECTION

"Smoothing the collection timing of kanban" means equally allocating time intervals for collecting kanban. If this cannot be strictly maintained,

[1] The above information is based on a paper written by Toyota staff. See Kuroiwa (1995).

the parts manufacturers cannot help but carry excessive stock, which will hinder them in their improvement efforts.

The basic rule is that during the working hours of one shift (7 hours and 40 minutes or 460 minutes) the kanban on Toyota's floor will be collected 12 times at equal intervals. Toyota divides one shift into 12 because, as stated previously, most parts manufacturers deliver with daily frequencies that are multiples of two: 2, 4, 6, 10, or 12 times a day. Since Toyota has adopted a two-shift system, the frequency of delivery in a shift is half the daily frequency, that is, 1, 2, 3, 5, or 6 times. Consequently, except for frequencies of five times, if Toyota collects kanban consistently 12 times per shift at their production site, they can give equal numbers of kanban to the parts manufacturers.

In March 1998, the working hours at Toyota were the following:

The first shift

6:30 8:30 8:40 10:40 11:25 13:25 13:35 15:15
|____|__|____|__|____|__|____|
Rest Lunch Rest

The second shift

16:15 18:15 18:25 20:25 21:10 23:10 23:20 1:00
|____|__|____|__|____|__|____|
Rest Lunch Rest

Because the working time of 460 minutes per shift divided by 12 equals about 40 minutes, collection of a smoothed number of kanban will be realized if they are collected at 40-minute intervals.

The working hours are divided into 12 from the time point when overtime is decided until the time point when the next overtime is decided. In other words, for two consecutive shifts, in the first shift, seven hours 40 minutes, from 13:35 until 23:10 of the next shift (excluding one hour and 55 minutes, the total amount of rest time), is divided into 12. This becomes the 40-minute interval. In the second shift, seven hours and 40 minutes, from 23:20 until 13:25 of the next shift, will be divided into 12.

During the above two shifts, if any overtime is introduced, an instruction for kanban-collection will be issued taking into account the entire working time: (460 minutes + overtime work during the shift) / 12.

A chime rings at the time when the kanban are collected. Because the collection interval is set differently for each assembly line, from the exit of coating to final inspection, the interval between chimes ringing varies depending on the line.

§ 4 INVENTIONS OF KANBAN POSTS AT THE PRODUCTION SITE

Even if the chief (e.g., the team leader) of a line comes to collect the kanban regularly, he may be late in making the collection. The chime rings at the time when the kanban are collected, but when the chief is late, even after the chime finishes ringing, operators continue putting kanban in the kanban post. Consequently, the actual number of kanban collected will increase.

The chief may be late collecting kanban for a number of reasons. For example, when he comes to the kanban post there is slight time difference if he walks around the site in a clockwise or a counterclockwise direction. Because the chief might be called upon suddenly, he may collect kanban a little later than the set time.

Consequently, even when we introduce the kanban method observing only its basic rules, we cannot necessarily achieve the original objective, which is production smoothing. For this reason, a new idea was introduced. Each kanban post has two boxes to receive kanban and each box has a lamp on it (see Figure 18.2).

The boxes that should receive the kanban at a particular time are lit. Boxes that should not receive the kanban at a particular time are not lit.

When line chiefs collect the kanban from the kanban posts at the production sites, the chime rings at each site. Immediately after the chime rings, another reception box will be lit. Consequently, kanban collectors pick up kanban from unlit boxes. This is a form of visual management. This device prevents changes in the number collected kanban collected because of kanban accumulation in the same box after the chime rings.

Parts Storage Site in the Assembling Factory

Different manufacturers use different-colored external frames on the kanban. In the factory, the colors of indicators at the parts storage site correspond to the kanban colors. Consequently, manufacturers can bring their

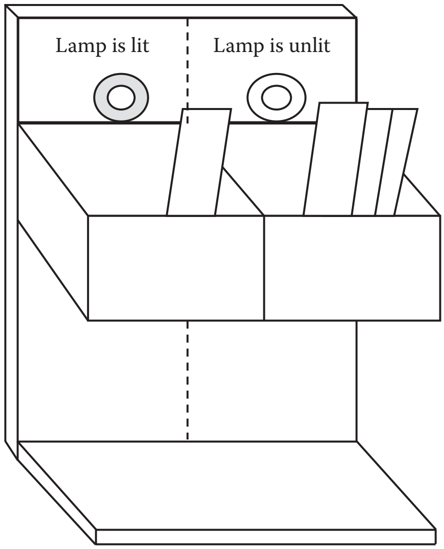


FIGURE 18.2
Two kanban reception boxes and lamps in the kanban post.

parts to the storage site that has indicators matching the color of their outgoing kanban. This is another form of visual management, a device for the parts manufacturers to deliver their parts just-in-time.

§ 5 POST-OFFICE MECHANISM FOR OUTGOING SUPPLIER KANBAN

The clerk's cabin, which is used for the kanban post office, is managed according to the following procedure:

Step 1: Kanban in the parts box on the production-line side are stored in the kanban reception post on the line side when an operator picks up the first part.

Step 2: Approximately once every 40 minutes, parts in the kanban reception post are collected and carried to the post office.

Step 3: In the post office, the supplier kanban goes through the sorter to be sorted automatically by each supplier's bar code.

Step 4: The sorted supplier kanban are stored on the sorting racks of the wall in the post office.

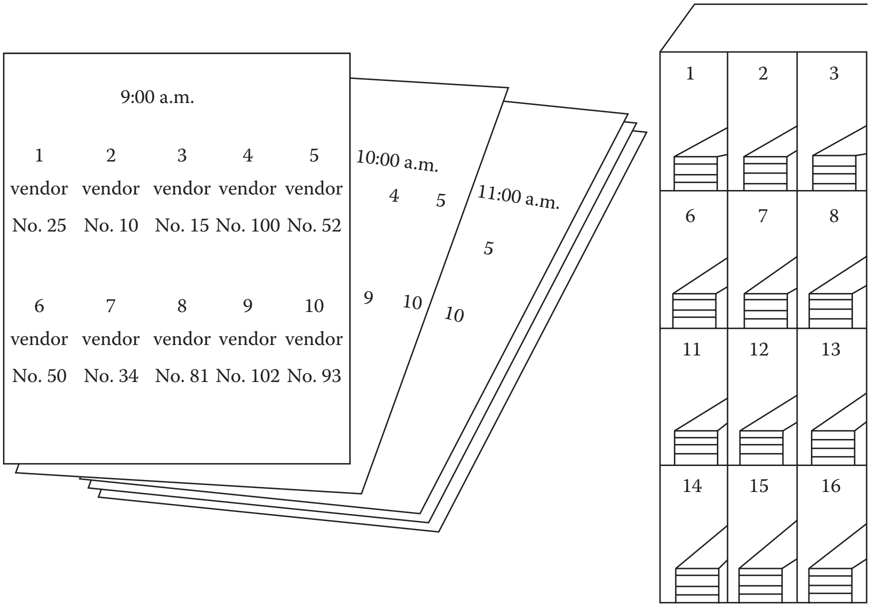


FIGURE 18.3
Hourly card listing of vendors' names in the supplier kanban sorting office.

When trucks from parts manufacturers arrive, kanban kept in the sorting racks are not handed to the truck drivers immediately because the trucks often arrive later or earlier than expected due to traffic conditions en route. As a result, when the driver is late, he picks up more kanban than expected and when the driver arrives early, he picks up fewer kanban than expected. Because of delays in truck drivers' arrival, the amount of outgoing parts may vary a great deal.

To avoid changing kanban quantities due to traffic conditions, Toyota adopts one important method. The sorting racks mentioned in step 4 above are located in the back (exit site) of the post office. Other sorting racks are set on the entrance wall to the post office. Near these racks, "list cards" with the parts suppliers to whom kanban should be handed are displayed every hour, and only the kanban of the suppliers listed on this card are placed on the sorting rack. The truck drivers receive their own kanban from the sorting rack at the entrance to the post office. (See Figure 18.3.)

As a result of this system, when a driver arrives earlier than expected, there are no kanban for him on the sorting rack at the entrance; until the list card is displayed, he has to wait. When he arrives later than expected, he receives the same number of kanban as he would have received if he had arrived at the expected time.

The idea of this system is similar to the two-kanban-post system with lamps depicted in the previous section.

19

Applying the Toyota Production System Overseas

Japan's share of the automobile market increases each year. In the American market, Japanese subcompact cars have become well accepted by American consumers. This is because of the now long-standing reputation of Japanese cars for high quality and value. Foreign and Japanese companies have shown a strong interest in transferring the Japanese production control system abroad. Is such a transfer possible? Environmental conditions among the companies are so different that the possibility of a transfer might have seemed impossible. On the contrary, the Japanese system is already being transferred. American motor companies have been achieving quality improvement and cost reduction by applying the Japanese production system to their manufacturing processes.

Toyota, Nissan, Honda, Matsuda, and Mitsubishi all established individual or joint ventures in the United States. Japanese parts makers have also entered into the American market either singly or by means of a joint venture and are bringing with them the Japanese production system.

Is international transfer of the Japanese production system by both countries' carmakers feasible? In other words, does the Japanese system have international applicability?

This chapter describes the situation when both American and Japanese auto manufacturers have tried their best to introduce and implement the JIT production system in the United States, especially during the 1980s. The business conditions between the two countries were fairly different at that time. These conditions have changed during the past 25 years, and so the contents of this chapter may seem to relate to past conditions rather than the current ones. However, this chapter does present how U.S. auto manufacturers have tried to apply JIT system to their country during the transplanting phase, which might be of some use and reference to many other countries, including Europe and emerging countries at present.

§ 1 CONDITIONS FOR INTERNATIONALIZING THE JAPANESE PRODUCTION SYSTEM

First of all, let us examine the social background by which the Japanese companies have attained such a strong competitive edge and define prerequisite conditions for international transfer. It was process innovation by improvement as well as product innovation by research and development that gave the Japanese motor industries the international competitive edge. Japanese automakers got their start after the Second World War by utilizing American and European development technology. However, in the automobile industry, in which development technology had been standardized, the superiority of Japanese management allowed Japan to gain control of its competition.

The innovative Japanese process control technology was originally created by Toyota and then spread to other Japanese companies. It is referred to as the Toyota Production System, or the just-in-time (JIT) production system. The foundation of the JIT production system is backed by social and institutional conditions peculiar to Japan. Here, the social conventions and the institutions supporting the Japanese production system can be called the social production system.

Two essential factors composing the social production system are (1) maker-supplier relationships and (2) management-labor relationships. While the educational system also has great influence on people's values, only the industrial conventions will be analyzed here.

The international transfer of the Japanese production system is possible if and only if the social environment of the country is altered to adapt to the new system. In the business field, a *contingency theory* has been advocated by P.R. Lawrence, J.W. Lorsch, and others, which says that formal organizational structure is a dependent variable to be defined by the environmental variables of technology, scale, and uncertainty. It has been theorized that an organization spontaneously establishes for itself the most effective organizational structure for the environment in which it exists. According to such a theory, the most efficient production systems for the United States and Japan are different because of differences in their respective environmental conditions.

Another school of thought proposes that a proficient management system can exist and be applied in any country. For example, the long-practiced lifetime employment system is not peculiar to Japan, but was also seen in American companies such as Kodak and Xerox.

My own theory is slightly different. In contingency theory, environment is viewed as a given factor and is also regarded as a non-operational, uncontrollable exogenous variable. But management does not always view the whole of the environmental conditions surrounding companies as a set of given factors. Environmental conditions are controllable in the long run and can be thought of as decision (endogenous) variables. Even the cultural aspect is changeable in the long run. For example, Buddhism was introduced into Japan (where only Shintoism had existed) and was absorbed spontaneously by the Japanese. It has since become very popular. Of course, some cultural or religious environments may be difficult to change initially.

The fact that American companies are regarded as possessions of the shareholders while Japanese companies are possessions of the employees is also difficult to change. The environmental conditions necessary for the smooth transfer of the Japanese JIT production system are the maker-supplier relationship and the management-labor relationship. These environmental conditions must be changed as a prerequisite to the introduction of the Japanese control system. Unlike Lorsch and Lawrence, I propose that the environmental conditions do not necessarily shape the organizational structure. Key environmental factors such as the maker-supplier relationship and the management-labor relationship can be changed to accommodate the introduction of a production control system. In order for the transfer of the Japanese system to work, these environmental conditions must be implemented.

§ 2 ADVANTAGES OF THE JAPANESE MAKER-SUPPLIER RELATIONSHIP

As described previously, international industrial competition relies largely on the superiority of the global social production system. When comparing the Japanese maker-supplier relationship with that of America's, two remarkable differences in the relationship between paternal companies and their contractors are revealed.

First, a hierarchy of subcontractor organizations forms the primary supply structure in Japan. This hierarchical structure has not normally been constructed in American companies. In the United States, the use of external suppliers has prevailed, but suppliers to subcontractors have not been sufficiently utilized. Whereas large American automobile manufacturers have historically had direct relationships with thousands of suppliers, Japanese carmakers purchase directly from several hundred, or fewer. Each level's paternal company in the hierarchical subcontract organization deals with as few as ten subcontractors in accordance with their management ability.

The second difference is that Japanese subcontracted companies get orders from one particular paternal company under a long-term contract arrangement. Nearly 38 percent of all Japanese subcontractors make 75 percent of their total sales to one paternal company. In total, 63 percent of the subcontracted companies rely on their primary paternal company for more than 50 percent of their total sales.

Considering the two features above, it is not surprising that the Japanese subcontract structure rests on the very close relationships between paternal companies and their subcontractors. These close relationships enable the easy transfer of information thus reducing transactions costs. Both the paternal companies and subcontractors reap the benefits of the subcontractors' growth in profits because of the production experience accumulated in long-term relationships. The criterion for being selected as a subcontractor is the ability to provide high quality, low cost, and short delivery time.

Regarding special technology, medium and small enterprises have been taken over by big companies, and a divisional system among varying technologies has been formed. This has created strong, competitive power for Japanese companies in international assembly-machining type industries. To be more specific, many subcontractors are providing their paternal companies with in-house programmed processes, new technology developed in-house, dies made in-house, exclusive use machinery developed and manufactured in-house, and original technologies.

In JIT systems, it is possible for Japanese subcontracted companies to react to hourly delivery schedules by using the kanban system. The JIT method can be attained through close relationships over a long period of time between a paternal company and a few subcontractors. The stable quality of the relationships is supported by high technology, and the shortening of production lead time is supported on the subcontractors' side. (See Figure 19.1.)

§ 3 REORGANIZATION OF EXTERNAL PARTS MAKERS IN THE UNITED STATES

Comparing the characteristics of parts makers in American and Japanese motor industries will highlight differences between the two. In Japan, the

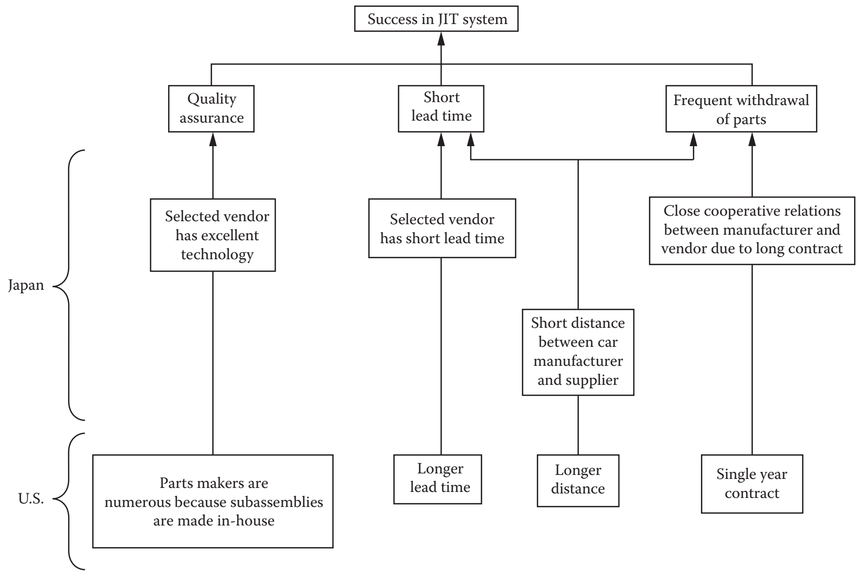


FIGURE 19.1
Comparison of transactions between manufacturer and supplier.

close cooperative relationships between parts makers and finished car manufacturers enabled the JIT system to succeed. In contrast, it was believed that there would be many problems in applying the JIT system in the United States due to the independence of American parts makers. However, this is a shallow viewpoint because Japanese parts makers as a group resemble the parts manufacturing divisions of American motor companies. In the United States, the parts manufacturing department within a company has the same close (dependent) relationship characteristics seen in Japan.

In Japan, most of the stock of primary parts makers is owned by the motor company. By contrast, this equity ownership does not exist between an American motor company and its parts supplier. The in-house manufacturing rate at American motor companies is so high that numerous terminal parts for subassembly are purchased from external parts makers. As a result, the number of parts to be purchased and the number of parts makers being dealt with is very large. Since the relationship with parts makers is not very reliable in terms of price and quality, the motor companies must maintain relationships with many parts makers.

To be competitive, the in-house manufacturing rate in American motor companies will have to decrease as will the number of parts makers that companies deal with. In regard to these points, let us examine how General Motors (GM) changed its dealings with external parts makers.

A GM assembly plant used to receive major parts in a predetermined quantity according to a calculation based on the average necessary quantity per day, but that quantity had not always matched the actual consumption rate of the plant. Once GM changed this plant to the JIT system and instructed its suppliers to deliver the necessary quantity of parts each day, this quantity matched the actual quantity consumed in the assembly plant.

The American car market has become very competitive since it was opened to Japanese parts makers. Other Japanese parts makers have followed Honda and Nissan in expanding their business to America. The establishment of a joint venture by Toyota and GM in California also fostered the extension of Japanese automakers. Although the primary role of such Japanese companies is to produce parts for Japanese car plants, they gradually and certainly will be strong rivals for domestic American parts makers.

As for GM, it was revealed that they changed their ordering policy. In steel transaction negotiations in 1984, GM selected steel plants on the basis of price, production quantity, and distance to GM stamping plants. Although GM did not abandon all twelve former suppliers at that time, they decided to centralize the orders to several subcontractors.

It is assumed that GM's purpose was to develop close relationships with its suppliers through annual contracts and a shared weekly production forecast to hold the inventory down to a minimum. This idea was borrowed from Japanese methods in which suppliers transport materials just-in-time corresponding to the motor companies' production schedules. Additionally, GM was trying to select suppliers that would further reduce the number of subcontractors. In July 1983, GM announced that it would decrease the number of steel suppliers, explaining that if the number of suppliers were reduced, those adopted by GM would be able to operate more economically, thereby leading to decreased steel costs.

Another reason for GM attempting to prolong contract periods with suppliers surfaced when the motor industry was recovering from a recession in 1981 to 1983. Any price hike demanded by parts makers would not be accepted; however, some of the parts makers were offered Japanese-like, multi-year contracts, which were considered to be an incentive for those suppliers to invest in automating factories and improving facilities. The advanced productivity made possible by such an investment would give bonuses in the long run to both parts makers and motor companies. For example, a three-year contract came out of the 1983 negotiations between tire manufacturers and motor companies. Although it involved a decrease in prices of about one percent, the subcontractor could depend on that business for three years instead of one.

§ 4 SOLUTION FOR GEOGRAPHICAL PROBLEMS INVOLVING EXTERNAL TRANSACTIONS

Another problem in applying the kanban system to parts delivery in the United States is the long distance between suppliers and carmakers in such a vast land. Most parts are conveyed by train or large trailer in the United States. In the case of rail transport, it takes about ten to twelve days from California to Detroit, and by truck, the same distance takes about seven or eight days. On average, one to three days are needed. A quantity of parts corresponding to this number of days is regarded as moving inventory.

When arriving at a plant, a trailer bearing a load is detached kept at a station exclusively for the storage of trailers. Then, the plant holds the parts for three to five days waiting for processing. Consequently, hundreds of large containers are left in the yard until a delivery dock foreman directs unloading of the parts. Because of the long conveyance distance, distribution costs necessarily increase, and thus the frequency of conveyance decreases. It is normal to deliver units by a large trailer from one to three times a week.

The author suggested in May 1981 that American automobile companies "should look for a means of adopting subcontractors located closer geographically" (Monden 1981). Thereafter, GM adopted a system that closely resembles this in Buick City in Flint, Michigan. General Motors gathered its parts makers around this main plant, Buick City, and asked them to produce and deliver parts by the kanban system. This industrial area was started in 1985 along the same lines as the Mikawa district in Aichi, where Toyota realized the kanban system by centralizing its parts makers nearby.

According to the plan, 83 percent of the parts were to be produced within a 100-mile radius of Buick City, and 100 percent were to be produced within a 300-mile radius. This meant that all parts could be delivered within eight hours and inventory could be reduced from eight days' worth to four hours' worth in regard to main parts, and from twenty days to only five days in regard to engine parts. However, it is regrettable that

Buick City became very depressed as the documentary film *Roger and Me* showed because of the recession due to decreased sales.

The next adjustment between Japanese motor companies and parts makers is often carried out through associations established by each motor company. Toyota has three types of associations for parts makers within each district. (Each of these associations consists of 137 firms, 63 firms, and 25 firms, respectively.) Furthermore, big parts makers have their own organizations. In the United States, these types of associations did not exist at all until the 1980s. In January 1983, the Japan GM Association was organized. This association is made up of almost 100 companies including Japanese parts makers such as TDK, NEC, National, Hitachi, Funuk, machinery makers, and robot makers for industry.

General Motors expanded its use of the JIT system in the following way. A large assembly plant was built in Orion, Michigan, by the assembly division of GM. In this plant, to realize the JIT system, parts were delivered by trucks, not trains, to a parts arrival point. Also, at the Hamtramck plant in Detroit, 48 truck starting points were located near workshops using the materials. This is in contrast to the previous system GM used in which large containers were controlled at huge stations and unloaded at only one receiving dock before finally being transported to a storage facility. In Buick City, receiving docks were located at 100 m intervals. As parts arrived, they could be immediately taken to the assembly line.

As previously mentioned, in Japan usually only one or two parts makers are used for purchasing particular parts, whereas in the United States many parts makers are used. Geographic location can sometimes make it difficult for parts makers to react to production demand. Additional complications, such as a blizzard in the Midwest, may force plants in the South to stop their operations, hindering the delivery of parts. Or, a strike at a plastic plant in California may force electronics companies in New York to stop their operations.

§ 5 EXTERNAL TRANSACTIONS OF NUMMI

How were external transactions performed at New United Motor Manufacturing, Inc. (NUMMI)? NUMMI was a joint venture between Toyota and GM established in 1984 with fifty-fifty capital investments of both companies, as a symbol of the mutual friendship of U.S./Japan auto industries, which were both confronted with severe automobile trade friction. This is an interesting subject because the Toyota Production System was applied to this company for the first time in the history of American automobile manufacturing. Also, NUMMI was the only one of the seven Toyota plants in North America where the employees belonged to the United Auto Workers Union (UAW). Therefore, examining how the Toyota Production System was applied at NUMMI is very useful when considering overseas applications. However, it was very regrettable that both companies had to make the decision to withdraw from NUMMI in 2009, as a result of overcapacity in North America caused by the recession.

Parts required at NUMMI were produced in America but were also produced in and transported from Japan. For example, about 1,500 types of parts for the subcompact car Nova were sent from Japan, and most of them were manufactured at Toyota and its subcontracted companies.

At one time, New United Motor Manufacturing, Inc., had business relations with 75 suppliers in North America, and 700 kinds of parts for the Nova were purchased from those companies. Fifty-five out of 75 suppliers were located in the Midwest, six in the Southeast, three in Mexico, and eleven in California. These parts suppliers were regarded as members of the NUMMI team, so naturally mutual trust and respect between NUMMI and the suppliers was cultivated and maintained. Since this sort of friendly automotive relationship, while typical in Japan, is fairly rare in the United States, special consideration was taken in evaluating and selecting the suppliers. General selection criteria, such as quality, price, location, and so on, were important, but the supplier's cooperative attitude was the most significant factor. The suppliers were examined to see if they could willingly accept the constraints of a new production system.

Team members from its production control, quality, manufacturing, and purchasing departments at NUMMI were dispatched to supplier's facilities. These team members provided training, support for problem solving, and assistance in practicing kaizen. In general, they worked to strengthen the relationship between NUMMI and the parts makers. Periodic parts-maker conferences were held in which common problems were discussed, and information concerning future events was provided.

Suppliers in North America were given a weekly forecast of requirements. This forecast contained seven weeks of part number level shipping requirements. This preliminary schedule was used only for planning purposes; it did not signify a commitment by NUMMI (resembling the three-month forecast in Japan). The forecast was either

1. Number of part makers reduced.
2. Contract period extended.
3. In-house manufacturing rate of parts decreased.
4. Proximity of part maker to manufacturer considered (i.e., Buick city).
5. Local association of part makers established.
6. Joint effort between Japan and U.S. car manufacturer established.
7. Team members from NUMMI dispatched to part makers.

FIGURE 19.2
Changes of transaction convention in the United States.

delivered by airmail or transmitted electronically to parts makers. While the preliminary schedule was updated weekly for seven weeks, the final requirement quantity was issued once to parts makers, two days before the shipment date. The parts makers were telephoned, or instructed through other electronic communications as to what the final requirement schedule regarding the specific day's shipment would be. This final requirement schedule was the commitment to the parts makers. As most parts were shipped every day, the final requirement schedule was communicated daily.

This final requirement schedule was based on the actual consumed quantity of parts in NUMMI's production process. The actual usage was calculated by counting the kanban cards for materials or parts used in a day's production. To refine this calculated quantity, miscellaneous usage and expected future schedule adjustments (overtime, holidays, etc.) were considered. The changes in the methods of transactions described up to now are summarized in Figure 19.2.

§ 6 INDUSTRIAL RELATIONS INNOVATIONS

According to Prof. Kuniyoshi Urabe (1984), transferring the JIT system to the United States is not impossible, but it is obvious that the differences in industrial relations between America and Japan have been large obstacles. A discussion of the obstacles follows.

Prerequisites of Flexible Labor Systems

Under the JIT system, it is a prerequisite that worker transfer within a plant, exclusive of worker transfer between plants, be performed without restriction. In this manner, a flexible labor system is realized. Specific institutional features, i.e., educational training, wage system, and labor-management relations, which are inherent in Japanese companies, serve as the basis for and enable a flexible workforce. Japanese companies provide the necessary training for employees to become multi-functional workers who can handle various jobs.

The Japanese wage system has traditionally been based on seniority. The wage system depends on a person's attributes. In other words, attributes such as academic career and years of work experience are evaluated in deciding each person's salary, not the content of the work itself. Although the Japanese wage system has been changing to a job-class wage system having a competitive aspect and to a qualification-ordered wage system, wages are mainly decided by considering attributes. Because of the attribute-ordered wage system in Japan, the transfer of workers to different jobs in response to the needs of the company does not pose a problem.

In contrast, American companies apply the job-class wage system in which one is paid on the basis of the job itself. Under the JIT system, if a worker is transferred to another type of job in the United States, problems will occur because the transfer might involve a change of job and thus of wage classification. If a worker is transferred to a lower-ranked job classification, it will mean a cut in wages and a major labor-management dispute.

The Japanese wage system is a fixed daily or monthly wage system. In the United States, most laborers are paid according to an hourly or weekly wage system, and an incentive wage system is the most common. The incentive wage system is one in which a worker can achieve additional wages if certain predetermined standards of operations are achieved. Although this standard of operations is based on a time and motion study, it becomes under American industrial relations subject to collective bargaining with the union. After the transfer of a worker, a standard of operations for the new job must be discussed between members of the union and the company. Some labor unions have a clause in the labor agreement keeping the tradition of craft unions in which worker transfers among different kinds of jobs falling under different union jurisdictions are prohibited. Since automobile assemblers and machinists who make parts are different occupations requiring different skills, the transfer of workers between these jobs is prohibited. Even if worker transfer between different jobs is allowed, if seniority rule is one of the articles of the labor contract, the transfer to a requested workplace is granted to workers by reason of seniority at the present job.

Prerequisites of Workplace Improvements

Under Japanese industrial relations, matters within a manufacturing process, such as reduction in the workforce, improvement of methods and standards of operations, and automation of machinery are not a part of the collective bargaining process, although they can become a topic of dispute between labor and management. In Japan, only basic labor conditions (i.e., salary, extra income based on company profits, and labor hours) are brought up as subjects of collective bargaining, and sometimes as issues to go to strike over.

American industrial relations are fundamentally hostile. If a reduction in workforce is desired, management and labor must reach an agreement through collective bargaining or it will not be possible to implement such a change. The union might resist a reduction in workforce. Even matters within the manufacturing process itself that have great influence over the advancement of quality and productivity, such as the improvement of operation methods and the automation of machinery, have become subject to the collective bargaining process because they affect labor conditions in the workplace.

The features of American industrial relations described above have been changing in an attempt to introduce the Japanese production system. A discussion of these attempts follows. (See Figure 19.3.)

Features of New Labor Contracts

New United Motor Manufacturing, Inc. concluded a labor contract with the United Automobile Workers Union (UAW), aimed at eliminating all obstacles to the introduction of the Toyota Production System. According to Mr. Thompson (1985), a production management chief at NUMMI, NUMMI had been operating with two-shift production since early 1986. Eighty-five to 90 percent of the 2,500 employees were paid on an hourly basis and represented by the UAW. The balance consisted of unrepresented salaried personnel.

The new labor contract included three points.

Point 1

While there were 31 job classifications in the UAW, NUMMI had only two classifications for hourly employees:

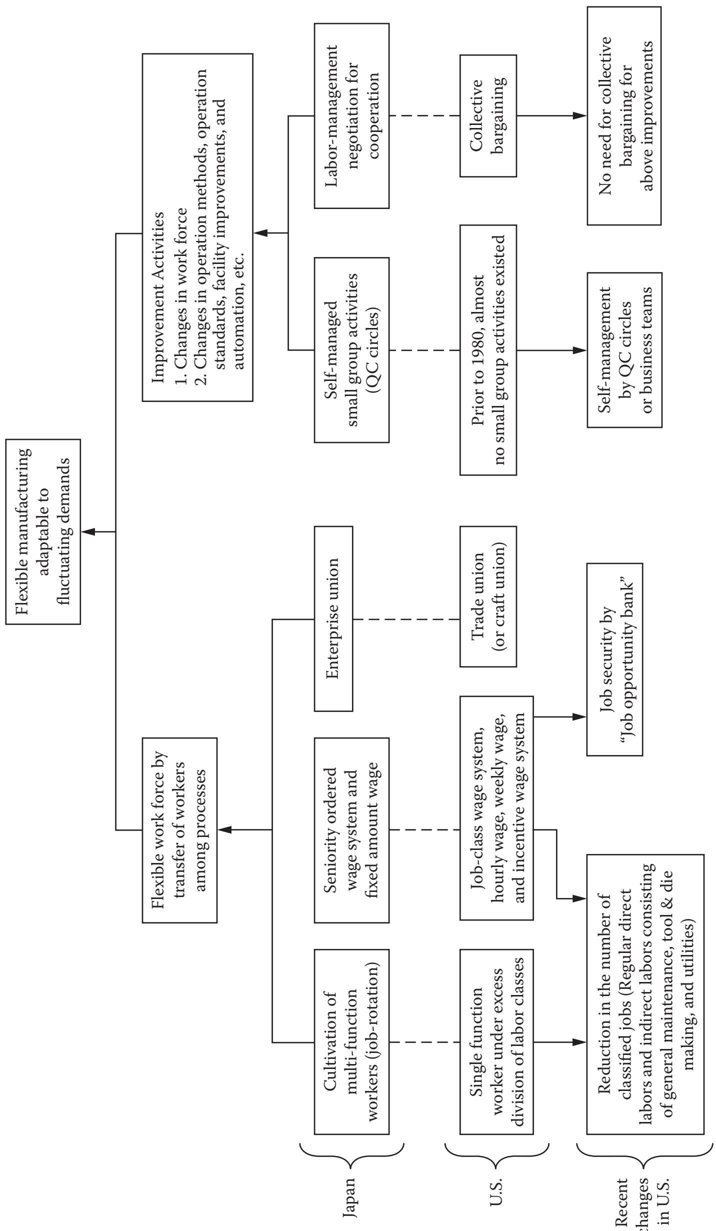


FIGURE 19.3
Labor–management relationship.

1. Division 1—regular direct labor
2. Division 2—indirect labor

These were skilled positions further divided into three classifications: general maintenance, tool and die maintenance, and utilities. As a result of simplifying the job classifications, worker transfer became easier within each division, and the goal of having a multi-functional workforce was achieved.

Point 2

The workers were organized into teams similar to Japanese quality control circles. Each team consisted of five to ten members, including an hourly-paid team leader. This team leader was similar to a coach for a sports team. Three to five teams were collectively supervised by a group leader, the first-level salaried supervisor, and reported directly to him. The group leader reported to either a manager or an assistant manager.

It should be noted that each team operated autonomously, taking full responsibility for manufacturing, quality, cost, safety, and other work goals. In short, the team set its goals and worked together to attain them. The team leader was a working member who had the capability and knowledge to deal with every operation proficiently as well as to motivate the team. Team leaders trained and looked after other team members, maintained safety and training records, and assisted the group leader with the management and functioning of the team.

All team leaders and group leaders (more than 300 total) were sent to Japan and given actual training at a Toyota assembly plant so that they could understand the Toyota Production System and Japanese management techniques in general. Toyota also dispatched 200 people to NUMMI as instructors. These Toyota instructors worked at NUMMI for three to four weeks. Also, Toyota assigned twenty-four management personnel to supervise each manager to assure the coordinated application of the Toyota Production System.

Point 3

The alteration of production systems and standards, which formerly required negotiations between management and labor unions, was easily executed, thereby making the flexible manufacturing system feasible. All changes in machinery, materials, labor utilization, and even the details of the production system were possible without union negotiations.

It is said that the corporate culture or business climate was changed to a system of mixed Japanese and American culture. It may be called an atmosphere of mutual reliance and respect. For example, the NUMMI plant had open office areas and one cafeteria. A first-come-first-served parking system, warm-up exercises in the morning, and uniforms were introduced. Sports facilities, team meeting rooms, and locker rooms were installed throughout the plant.

In the author's view, it is correct to present the full Japanese system to have the right foundation for the Toyota Production System. For the Toyota Production System to take firm root, not only are formal orientation and training programs needed, but also daily team meetings in which Toyota concepts are emphasized—for example, *jidoka* (autonomous automation), *kaizen* (improvement), *pokayoke* (mistake proofing), *muda* (waste), *five whys*, *heijunka* (smoothing), *kanban* (kanban system), *andon*, and so on. It is gratifying that the Japanese manufacturing management words are prevailing in the United States.

In 1984, a job *opportunity bank* system was introduced in a new labor contract between GM and the UAW. This job opportunity bank accepted members of the union who are likely to lose their jobs due to new technology, process changes, productivity improvement, or integration of parts manufacturing, and offered them opportunities for retraining for a job with an equivalent wage (provided the workers have more than one-year seniority).

A joint UAW-GM *employment assurance committee* constructed by management and labor at every level, district, and area established and organized job opportunity banks as necessary. The company provided ten billion dollars for its operation.

According to Prof. Haruo Shimada, introduction of this system provided a win-win situation. Management gained one method for management control of a flexible labor force and laborers enjoy the benefit of job security. In other words, by establishing this system, management obtained, with the order of parts, a business relationship with foreign enterprises and innovation of industrial technology.

The labor conditions described above, which did not previously exist in the American car manufacturing plants, allow for the flexibility needed to completely introduce the Toyota Production System. United States car manufacturers now have access to new production technology and have developed a strategic alliance with respectable foreign businesses.

§ 7 CONCLUSION

The transfer of Japanese production control techniques and Japanese management systems to other nations has occurred and is occurring as evidenced by the example of the joint venture between Toyota and GM. This transfer of technology and management principles can take on several forms:

1. The Japanese management system can be adapted to include American or European concepts such as reducing the workweek.
2. The Japanese management system could be implemented exactly as it operates in Japan.
3. A new management system could be created that would combine the technology of both countries. For example, the Japanese kanban system has been connected to the American MRP concept; also, robotics and a computer network system developed in the United States have been applied to the Japanese system.
4. A new cultural environment, conducive to implementing the Toyota Production System, could be initiated in the other country. Once achieved, the Japanese management system would be applied and adjusted to the new environment.

It is the author's opinion that one of the four scenarios described above will emerge as the most beneficial approach and that for JIT production systems to be implemented successfully the last approach would be the most appropriate.

Although basic differences in company concepts, culture, historical perspective, and regional affairs cannot be bridged overnight, creating new procedures, rules, thought processes, and so on, to apply the Japanese system is feasible. Regardless of how the transformation is accomplished, it should not be forced on the other country. On the contrary, the approach should be mutually agreed upon and planned by both countries. NUMMI was a symbol of the harmony between labor and management.

Section 3

Quantitative Techniques

20

Sequencing Method for the Mixed-Model Assembly Line to Realize Smoothed Production

The procedure for designing a mixed-model assembly line involves the following steps:

1. Determination of a cycle time
2. Computation of a minimum number of processes
3. Preparation of a diagram of integrated precedence relationships among elemental jobs
4. Line balancing
5. Determination of the sequence schedule for introducing various products to the line
6. Determination of the length of the operations range of each process

This chapter deals with the fifth step: The problem of sequencing various car models on the line.

§ 1 GOALS OF CONTROLLING THE ASSEMBLY LINE

The sequence of introducing models to the mixed-model assembly line is different due to the different goals or purposes of controlling the line. There are two goals:

1. Leveling the load (total assembly time) on each process within the line
2. Keeping a constant speed in consuming each part on the line

Goal One: Work Load Streamlining

Concerning Goal One, it is important to note that a product might have a longer operation time than the predetermined cycle time. This is in contrast with the fact that load leveling for the mixed-model line requires that the operation time for each model at each process does not exceed the cycle time. In other words, in terms of averages, the total of the operation time for all models, each weighted by its production ratio, should satisfy the following:

$$\max l \; \frac{\sum_{i=1}^{\propto} Q_i T_{il}}{\sum_{i=1}^{\propto} Q_i} \leq C,$$

Q_i = planned production quantity of the product A_i ($i = 1,\ldots,\alpha$)
T_{il} = operation time per unit of product A_i on the process l

$$C = \text{cycle time} = \frac{\text{total operation time per day}}{\sum_{i=l}^{\alpha} Q_i}$$

As a result, if products with relatively longer operation times are successively introduced into the line, the products will cause a delay in completing the product and may cause line stoppage. Therefore, a heuristic program can be developed for the assembly line model-mix sequencing problem to minimize risk of stopping the conveyor (for example, see Okamura and Yamashina [1979]).

Although this first goal is also considered in Toyota's sequencing program, it is incorporated in the solution algorithm, which mainly considers the second goal. As a result, Toyota considers most important the second goal of the sequence schedule: keeping a constant speed in consuming each part.

Goal Two and the Sequencing Model for Parts Usage Streamlining

In the kanban system used at Toyota, preceding processes supplying the various parts or materials to the line are given greatest attention. Under this "pulling" system, the variation in production quantities or conveyance times at preceding processes must be minimized. Also, their respective work-in-process inventories must be minimized. To do so, the quantity used per hour (i.e., consumption speed) for each part in the mixed-model line must be kept as constant as possible. Toyota's sequencing method is designed to reach this second goal. To understand this sequencing method, it is important to define several notations and values:

Q = Total production quantity of all products A_i $(i = 1,\ldots,\alpha)$

$= \sum_{i=1}^{\alpha} Q_i$, ($Q_i$ = production quantity of each product A_i)

N_j = Total necessary quantity of the part a_i to be consumed for producing all products A_i: $(i = 1,\ldots,\alpha;\ j = 1,\ldots,\beta)$

X_{jk} = Total necessary quantity of the part a_j to be utilized for producing the products of determined sequence from first to *Kth*.

With these notations in mind the following two values can be developed:

N_j/Q = Average necessary quantity of the part a_j per unit of a product.

$\frac{K \cdot N_j}{Q}$ = Average necessary quantity of the part a_j for producing K units of products.

To keep the consumption speed of a part a_j constant, the amount of X_{jk} must be as close as possible to the value of $K \cdot N_j / Q$. This is the basic concept underlying Toyota's sequencing algorithm and is depicted in Figure 20.1.

It can now be further defined that

$$\text{A point } G_k = (K \cdot N_1/Q, K \cdot N_2/Q, \ldots, K \cdot N_\beta/Q),$$

$$\text{A point } P_k = (X_{lk}, X_{2k}, \ldots, .X_{\beta k}).$$

In order for a sequence schedule to assure the constant speed of consuming each part, the point P_k must be as close as possible to the point G_k. Therefore, if the degree is measured for the point P_k approaching the point G_k by using the distance D_k:

$$D_k \| G_k - P_k \| = \sqrt{\sum_{j=1}^{\beta} \frac{K - N_j}{Q} - X_{jk} \quad 2}$$

then, the distance D_k must be minimized. The algorithm developed on this idea by Toyota is called the *goal-chasing method* (Figure 20.2).

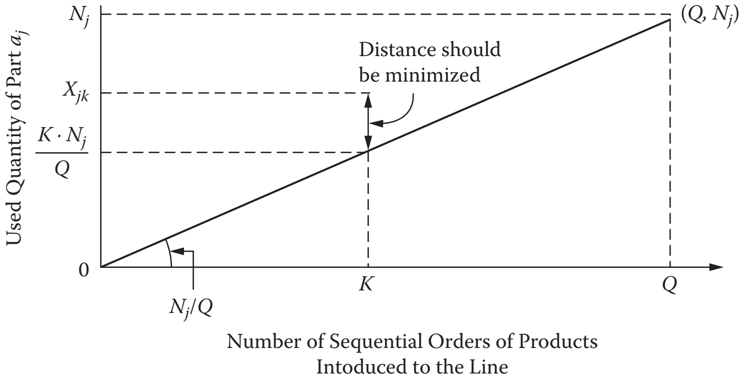


FIGURE 20.1
Relationship between X_{jk} and $K \cdot N_j/Q$.

§ 2 GOAL-CHASING METHOD: A NUMERICAL EXAMPLE

To fully understand Toyota's goal-chasing method, it is best to review an example. Suppose the production quantities Q_i ($i = 1, 2, 3$) of each product A_1, A_2, and A_3, and the required unit b_{ij} ($i = 1, 2, 3$; $j = 1, 2, 3, 4$) of each part a_1, a_2, a_3, and a_4 for producing these products are as shown in Table 20.1.

Then, the total necessary quantity (N_j) of the part a_j ($j = 1, 2, 3, 4$) for producing all products A_i ($i = 1, 2, 3$) can be computed as follows:

$$[N_j] = [Q_i]\,[b_{ij}]$$

$$= \quad 2,3,5 \quad \begin{matrix} 1011 \\ 1101 \\ 0110 \end{matrix} \quad = \quad 5,8,7,5$$

Further, the total production quantity of all products A_i ($i = 1, 2, 3$) will be

$$\sum_{i=1}^{3} Q_i = 2 + 3 + 5 = 10$$

Denote:

b_{ij} = Necessary quantity of the part a_i (j = 1,..., β) for producing one unit of the product A_i (i = 1,..., α).

Other notations are already defined.

Then,

Step 1 Set $K = 1$, $X_{j,k-1} = 0$, (j = 1,..., β), S_{k-1} = (1, 2, ..., α).

Step 2 Set as K th order in the sequence schedule the product A_i^* which minimizes the distance D_k. The minimum distance will be found by the following formula:

$$D_{ki^*} = \min\{D_{ki}\},\ i \in S_{k-1},\ \text{i}$$

$$\text{where } D_{ki} = \sqrt{\sum_{j=1}^{\beta}\left(\frac{K \cdot N_j}{Q} - X_{j,k-1} - b_{ij}\right)^2}.$$

Step 3 If some units of a product A_{i^*} were ordered and included in the sequence schedule, then

Set $S_k = S_{k-1} - \{i^*\}$.

If some units of a product A_{i^*} are still remaining as being not ordered, then set $S_k = S_{k-1^*}$

Step 4 If $S_k = \varnothing$ (empty set), the algorithm will end.

If $S_k \neq 0$, then compute $X_{jk} = X_{j,k-1} + b_{i^*j}$ (j = 1, ..., β) and go back to Step 2 by setting $K = K + 1$.

FIGURE 20.2

Goal-chasing method I.

TABLE 20.1

Production Quantities Q_i and Parts Condition b_{ij^*}

	Product A_t		
	A_1	A_2	A_3
Planned Production Quantity Q_j	2	3	5

Products A_i	**Parts a_j**			
	a_1	a_2	a_3	a_4
A_1	1	0	1	1
A_2	1	1	0	1
A_3	0	1	1	0

Therefore,

$$[N_j/Q] = [5/10, 8/10, 7/10, 5/10]$$

$$(j = 1,2,3,4)$$

Next, applying the values of $[N_j/Q]$ and $[b_{ij}]$ to the formula in step 2 of the above algorithm, when $K = 1$, the distances D_{ki} can be computed as follows:

$$\text{for } i = 1,\ D_{1,1l} = \sqrt{\frac{1\times5}{10}-0-1^{\;2} + \frac{1\times8}{10}-0-0^{\;2} + \frac{1\times7}{10}-0-1^{\;2} + \frac{1\times5}{10}-0-1^{\;2}}$$

$$= 1.11$$

$$\text{for } i = 2,\ D_{1,2} = \sqrt{\frac{1\times5}{10}-0-1^{\;2} + \frac{1\times8}{10}-0-0^{\;2} + \frac{1\times7}{10}-0-1^{\;2} + \frac{1\times5}{10}-0-1^{\;2}}$$

$$= 1.01.$$

$$\text{for } i = 3,\ D_{1,3} = \sqrt{\frac{1\times5}{10}-0-0^{\;2} + \frac{1\times8}{10}-0-0^{\;2} + \frac{1\times7}{10}-0-1^{\;2} + \frac{1\times5}{10}-0-1^{\;2}}$$

$$= 0.79.$$

Thus, $D_{1,i^*} = \min\{1.11, 1.01, 0.79\} = 0.79$

$$\therefore i^* = 3$$

Therefore, the first order in the sequence schedule is the product A_3. Proceeding to Step 4 of the algorithm,

$$X_{jk} = X_{j,k-1} + b_{3j}$$

$$X_{1.1} = 0 + 0 = 0$$

$$X_{2.1} = 0 + 1 = 1$$

$$X_{3.1} = 0 + 1 = 1$$

$$X_{4.1} = 0 + 0 = 0$$

K	D_{k1}	D_{k2}	D_{k3}	Sequence Schedule	X_{1k}	X_{2k}	X_{3k}	X_{4k}
1	1.11	1.01	0.79	A_3	0	1	1	0
2	0.85	0.57*	1.59	$A_3\,A_2$	1	2	1	1
3	0.82*	1.44	0.93	$A_3\,A_2\,A_1$	2	2	2	2
4	1.87	1.64	0.28*	$A_3\,A_2\,A_1\,A_3$	2	3	3	2
5	1.32	0.87*	0.87	$A_3\,A_2\,A_1\,A_3\,A_2$	3	4	3	3
6	1.64	1.87	0.28*	$A_3\,A_2\,A_1\,A_3\,A_2\,A_3$	3	5	4	3
7	0.93	1.21	0.82*	$A_3\,A_2\,A_1\,A_3\,A_2\,A_3\,A_3$	3	6	5	3
8	0.57*	0.85	1.59	$A_3\,A_2\,A_1\,A_3\,A_2\,A_3\,A_3\,A_1$	4	6	6	4
9	1.56	0.77*	1.01	$A_3\,A_2\,A_1\,A_3\,A_2\,A_3\,A_3\,A_1\,A_2$	5	7	6	5
10	—	—	0*	$A_3\,A_2\,A_1\,A_3\,A_2\,A_3\,A_3\,A_1\,A_2\,A_3$	5	8	7	5

FIGURE 20.3
Sequence schedule. (*Note:* * indicates smallest distance D_{kj}.)

Thus, the first line in Figure 20.3 was written based on the above computations.

Next, when $k = 2$, then

$$\text{for } i = 1,\ D_{2.1} = \sqrt{\left(\frac{2\times5}{10}-0-1\right)^2+\left(\frac{2\times8}{10}-1-0\right)^2+\left(\frac{2\times7}{10}-1-1\right)^2+\left(\frac{2\times5}{10}-0-1\right)^2}$$

$$= 0.85.$$

$$\text{for } i = 2,\ D_{2.2} = \sqrt{\left(\frac{2\times5}{10}-0-1\right)^2+\left(\frac{2\times8}{10}-1-1\right)^2+\left(\frac{2\times7}{10}-1-0\right)^2+\left(\frac{2\times5}{10}-0-1\right)^2}$$

$$= 0.57.$$

$$\text{for } i = 3,\ D_{2.,3} = \sqrt{\left(\frac{2\times5}{10}-0-0\right)^2+\left(\frac{2\times8}{10}-1-1\right)^2+\left(\frac{2\times7}{10}-1-1\right)^2+\left(\frac{2\times5}{10}-0-0\right)^2}$$

$$= 0.57$$

Thus, $D_{2i^*} = \text{Min}\ \{0.85, 0.57, 1.59\}$

$= 0.57.$

$\therefore i^* = 2.$

Therefore, the second order in the sequence schedule is the product A_2. Also, X_{jk} will be computed as

$$X_{jk} = X_{j,k-1} + b_{2j^*k}$$

$$X_{1,2} = 0 + 1 = 1$$

$$X_{2,2} = 1 + 1 = 2$$

$$X_{3,2} = 1 + 0 = 1$$

$$X_{4,2} = 0 + 1 = 1$$

This procedure was used to develop the second line of Figure 20.3. The remaining lines in Figure 20.3 can also be written by following the same procedures. As a result, the complete sequence schedule of this example will be:

$$A_3, A_2, A_3, A_3, A_{2,} A_3, A_3, A_{1,} A_{2,} A_{3.}$$

Evaluation of the Goal-Chasing Method

The values of $K \cdot N_j/Q$ and X_{jk} for each part a_j in the previous example are depicted as graphs in Figure 20.4. The figure shows that all parts a_1, a_2, a_3, and a_4 are attaining optimality.

The meaning of *optimality* in this section is as follows: Suppose $[[K \cdot N_j/Q]]$ denotes the integer which is closest to $K \cdot N/Q$.

Then, if $X_{jk} = [[K N_j/Q]]$ holds for the part a_j, the optimality is achieved in this part. Figure 20.4 shows all parts attaining optimality on this evening.

To further evaluate this algorithm, the mean and the standard deviation of the values were computed:

$$\frac{K \cdot N}{Q} - X_{jk} \quad \text{for each part } a_j$$

Then, the following results were found:

- When the number of varieties in parts items and/or the number of varieties in product-models were increased, both the mean and the standard deviation were increased.
- When the production quantity itself was increased, both the mean and the standard deviation were decreased.

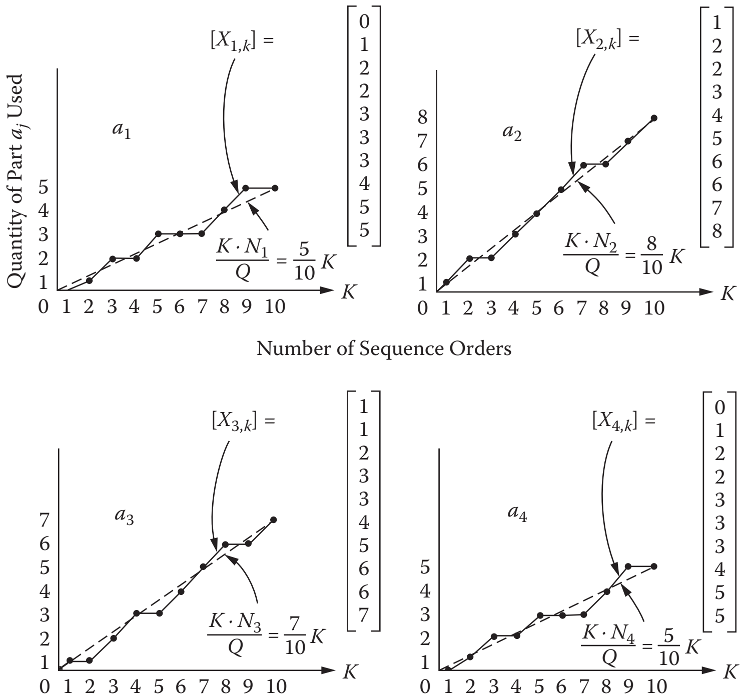


FIGURE 20.4
How X_{jk} approached $K \cdot N_j/Q$.

It is clear from these results that the more the tendency to produce multi-varieties in each small quantity is promoted, the less likely smoothing of production will be attained.

Another general approach for verifying the usefulness of this heuristic algorithm is expressed by the following procedure. Suppose the total production quantity

$$Q = \sum Q_j$$

is large (1,000 units, etc.). Then, the sequence determined by this algorithm can be divided into 16 equal ranges, with each range corresponding to approximately one hour of production. The quantity of each part contained in each range will be computed, and its standard deviation will be computed. The actual distribution of these values shows that the variation (σ) per hour is fairly small (see Figure 20.5). The coefficient of variation $(= \sigma/\overline{x})$ in each range is small and its variance is also small.

Kind of front axies \ Range	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	$\bar{x}$	σ
a_1	9	7	7	9	8	7	8	8	8	8	7	8	9	7	7	8	7.8	0.73
a_2	6	5	7	6	5	6	7	5	7	6	5	7	6	6	5	6	5.9	0.75
a_3	5	6	5	5	6	6	4	6	4	6	6	5	4	6	5	6	5.3	0.77
a_4	3	3	3	2	3	3	3	3	3	2	3	3	3	2	3	3	2.8	0.33
a_5	2	2	2	2	3	2	2	2	2	3	2	1	3	2	2	2	2.1	0.48
a_6	1	1	1	1	1	2	1	1	2	0	2	1	1	1	1	1	1.1	0.48

FIGURE 20.5
Distribution of each kind of front axle used.

$$E_{ki} = \max \{E_{ki}\}, \ i \in S_{k-1}$$

$$\text{where } E_{ki} = \sum_{j_{i \in Bi}} \left(\frac{K \cdot N_{ji}}{Q} - X_{ji,\,k-1} \right)$$

(B_i is a set of constituent parts a_{ji} for the product A_i)

FIGURE 20.6
Goal-chasing method II.

§ 3 THE TOYOTA APPROACH: A SIMPLIFIED ALGORITHM

To decrease computational time, a simplified algorithm known as *goal-chasing method II* (Figure 20.6) can be developed. This simplified algorithm is evolved from Step 2 of goal-chasing method I (Figure 20.2) and is based on the following proposition:

Among a product A_b and the other product A_c,

if $D_{k.b}$ ″ $D_{k.c,}$ then the relationship

$$\sum_{j_b \in B_b} \frac{K \cdot N_{jb}}{Q} - X_{jb,K-1} \geq \sum_{j_b \in B_c} \frac{K \cdot N_{jc}}{Q} - X_{jc,K-1}$$

will hold and vice versa, and where B_b is a set of constituent parts a_{jb}, for the product A_b. This equivalence relationship can hold under the condition that the number of items of parts used for each product must be the same among different products and that the necessary quantity of each part used for one unit of each product must be the same among different products.

The process to prove this proposition is as follows:

Denote:

W = necessary quantity of each item of part for a unit of a product, then,

$$D_{k,c}^2 - D_{k,b}^2 = \sum_{j_c \in B_c - B_b} \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1} - W\right)^2 - \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1}\right)^2$$

$$+ \sum_{j_c \in B_c - B_b} \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1}\right)^2 - \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1} - W\right)^2$$

$$= -W \sum_{j_c \in B_c - B_b} \left(2\frac{K \cdot N_{jc}}{Q} - 2X_{jc,k-1} - W\right)$$

$$+W \sum_{j_c \in B_c - B_b} \left(2\frac{K \cdot N_{jc}}{Q} - 2X_{jb,k-1} - W\right)$$

$$= -2W \sum_{j_c \in B_c - B_b} \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1}\right) + 2W \sum_{jc \in B_b - B_c} \left(\frac{K \cdot N_{jb}}{Q} - X_{jb,k-1}\right)$$

(because $|B_c - B_b| = |B_b - B_c|$ due to the assumption.)

$$= -2W \sum_{j_c \in B_c - B_b} \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1}\right) + 2W \sum_{j_c \in B_b - B_c} \left(\frac{K \cdot N_{jb}}{Q} - X_{jb,k-1}\right)$$

$$+ 2W \sum_{S \in B_c \cap B_b} \left(\frac{K \cdot N_s}{Q} - X_{s,k-1}\right) - \left(\frac{K \cdot N_s}{Q} - X_{s,k-1}\right)$$

$$= 2W \sum_{j_b \in B_b - B_c} \left(\frac{K \cdot N_{jb}}{Q} - X_{jb,k-1}\right) + \sum_{s \in B_c \cap B_b} \left(\frac{K \cdot N_s}{Q} - X_{s,k-1}\right)$$

$$- 2W \sum_{j_b \in B_c - B_b} \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1}\right) + \sum_{s \in B_c \cap B_b} \left(\frac{K \cdot N_s}{Q} - X_{s,k-1}\right)$$

$$= 2W \left(\sum_{j_b \in B_c} \left(\frac{K \cdot N_{jb}}{Q} - X_{jb,k-1}\right) - \sum_{J_c \in B_c} \left(\frac{K \cdot N_{jc}}{Q} - X_{jc,k-1}\right)\right)$$

Thus, the equivalence relationship was proved.

Sequence Scheduling in the Practice: An Example

It is difficult to apply the goal-chasing method since the number of different parts used in an automobile is about 20,000. Therefore, the parts are represented only by their respective subassembly, where each subassembly has many outputs. For example, a car brand may have the following production data:

- Planned production quantity = about 500 (= number of sequence orders).
- Number of kinds of cars = about 180 (therefore, each kind has about three units).
- Number of subassemblies = about 20. The main subassembly names are as follows:

    1. Body types
    2. Engines
    3. Transmissions
    4. Grades (series)
    5. Frames
    6. Front axles
    7. Rear axles
    8. Colors
    9. Bumpers
    10. Steering assemblies
    11. Wheels
    12. Doors
    13. User's countries
    14. Air conditioners
    15. Seats
    16. etc.
    17. "
    18. "
    19. "
    20. "

Note that each subassembly must obviously contain many different parts. To the number of subassemblies the difference in loads (assembly hour) of various cars must be added to handle it in the same way as real parts.

Using the above data, a sequence schedule was developed by using goal-chasing method II. Then, the sequence was divided into 16 equal ranges (each range corresponded to about one hour of production time). Using front axles as an example, refer to Figure 20.5 to see how many units of each kind of front axle were included in each range. Obviously from the figure, it can be seen that the value of the standard deviation (σ) displays a small variation of speed of utilizing each part.

§ 4 SIMULTANEOUS ACHIEVEMENT OF TWO SIMPLIFYING GOALS

So far, only one goal has been considered to keep a constant speed in the utilization of each part on the mixed-model assembly line. However, another goal—to avoid successive proceedings of the products that have a larger load of assembly time—must also be considered.

In general, the kind of product that has a larger load is different when a different process is considered for the product in question. Toyota's line balancing is designed so that the car model that has a larger assembly time always has larger loads at every process in the line. To avoid introducing successively the same product requiring a longer operation time, all automobiles on the line are classified according to large (a_l), medium (a_m), or small (a_s) total assembly times. Each a_j (j = 1, m, and s in this situation) must be introduced to the line so as to keep the speed constant on the line. This goal can be achieved by using the same simplified algorithm for keeping the speed constant of utilizing each part a_j on the line.

In practice, Toyota "weights" important subassemblies and in some cases, provides some additional constraints such as facility capacities, and so on. The classified categories (a_l, a_m, a_s) of assembly time loads are also given some weight to solve the conflict between the line balancing goal and the part smoothing goal.

This chapter is based on a presentation by Mr. Shigenori Kotani (staff member of the production control department at Toyota Motor

Corporation) at the conference of the Japan Operations Research Society, March 25, 1982, and his abstract (pp. 149–150) in the proceedings of this conference. This chapter is also based on follow-up discussions with Mr. Masuyama, Mr. Terada, and Mr. Kotani of Toyota Motor Corporation. The numerical examples here (except Figure 20.5) are made by the author.

21

New Sequence Scheduling Method for Smoothing

Toyota's quantitative method used for the sequence scheduling of models to a mixed-model assembly line (the goal-chasing method described in the previous chapter) has evolved to a new version. Since this new method has a function to include multiple goals, I will call it the goals-coordinating method in this book. Furthermore, various improvement techniques to decrease the differences in assembly hours among models in an assembly line will be introduced.

§ 1 BASIC LOGIC OF SEQUENCE SCHEDULING

The two main logical components of the sequence scheduling method for smoothing in an assembly line are the *appearance ratio control* and the *continuation and interval controls*. Appearance ratio control, or control by an average appearance ratio, can be defined as setting a target for the average "appearance ratio" of various items or specs and smoothing their appearances on the assembly line. The sequence schedule for vehicles should be prepared in accordance with this average ratio. The appearance ratio is calculated using the following formula:

$$\text{Appearance ratio} = \frac{\text{Total number of vehicles of certain spec}}{\text{Total number of all vehicles}}$$

This is the goal-chasing method explained in the previous chapter. It results in selecting, one by one, those models that minimize the total deviation between an objective value of consumption based on the average appearance ratio and an actual consumption value for specs and parts to be smoothed.

Appearance ratio control cannot solve all the problems posed in the sequence scheduling. In reality, the strain caused by a daily scheduling process is shifted to about 10 percent of vehicles sequenced around the end of the day. This shift means that the distance from the line of the average use or average appearance of each part or spec will be longer. Stated differently, smoothing in sequence can hardly be realized in the final 10 percent of cars produced in a day.

To solve this problem it would be possible, for instance, to introduce additional constraints that preserve the product rate; that is, the original ratio of the number of units of each model variant to the total number of units of all model variants. There are many possibilities for developing such constraints.

The problem of smoothing the assembly workload cannot be solved by applying only the appearance ratio control described above. This problem could be solved by using the goal-chasing method in a manner similar to that for appearance ratio control for the specs, where the specs are replaced by the workload categories described in the previous chapter.

In this chapter, however, we introduce continuation and interval controls for achieving the workload smoothing goal. These controls are defined as follows:

1. *Continuation control* directs the continuation of vehicles of a certain spec so that they do not exceed a designated maximum number of units. For example, two cars with the same spec may be approved to flow successively, but the third car must be different from the spec of the first two cars.
2. *Interval control* keeps the interval of units between the two same vehicles of a certain spec within a designated minimum interval. Suppose a spec B car (e.g., a car with grade H) is introduced with an interval of not less than three cars. The rule states that even if the *appearance ratio control* (goal-chasing method) selects the spec B car again as the third car, the second-best spec C must be introduced instead of the spec B car.

In this manner, the appearance ratio control of the goal-chasing method is used as the main logic of the sequencing method, while the logic of continuation and interval controls is used as a restricting condition to the main logic.

The sequence in which models are introduced is initially determined by applying the appearance ratio control to the first car in the sequence. Each selected car is then examined to determine whether it also satisfies the rules of the continuation and interval controls. If a car that does not meet the rules is encountered, another car with the optimum spec will be selected by applying the appearance ratio control to the remaining cars while ignoring the spec in question.

If the maximum number of cars having sunroofs in a sequence is two, the sequence of a vehicle will be as above. Out of the vehicles without a sunroof, the car that minimizes the amount of the total deviation in the following formula should be selected as the *Kth* car.

$$\sum_{j=1}^{n}\left|\frac{A\times K}{B}-(C+D)\right|$$

where
A = Total number of vehicles of a given spec j
B = Total number of vehicles
C = Accumulated number of spec j up to *(K-1)th* vehicle
D = Number of units of spec j of *Kth* additional vehicle
n = Total number of specs for models to be sequenced

Parts 1 and 2 of Figure 21.1 show actual computer input data concerning the appearance ratio control and the continuation and interval controls.

Assisting Rules

The following three assisting rules are used to determine parameters of the previous two restricting rules (continuation and interval controls).

1. *Weighting control.* If it is desirable under the appearance ratio control to realize an objective value of the average appearance ratio for a certain spec in preference to other specs, a relatively bigger weight is given to such a ratio. Attention must be paid to the fact that the expected weight for smoothing a certain spec is different among different processes. For example, in an assembly

Computer Data Conditions of Model A **Nov. 1993**

End items	Contents of input data		Process		
	Appearance ratio control	Continuation & interval control	W	T	A
Panoramic roof + sun roof	○	min. interval of 2 vehicles ④	○	○	○
Sun roof	○	min. interval of 2 vehicles ①	○		
5-door van	○	min. interval of 4 vehicles ⑥	○	○	○
Type of engine	○				○
Transmission	○				○
2-tone color	○	min. interval of 2 vehicles ⑪		○	
Grade	○	min. interval of 4 vehicles (Q grade) ⑦	○		○
Wagon	○	max. continuation of 4 vehicles ⑬			○
Automatic curtain	○	min. interval of 4 vehicles ⑧			○
Power-steering	○	min. interval of 3 vehicles ⑩			○
All metallic color	○	min. continuation of 2 vehicles ⑫		○	
Van + space wagon	○	min. interval of 3 vehicles (van) ③	○		○
Interior color	○				
4WD + 2WD	○	min. interval of 2 vehicles (4WD) ② min. continuation of 2 vehicles (2WD) ⑤	○		○
Suspended roof	○	min. interval of 3 vehicles ⑨			○
2-tone & roof	○				

FIGURE 21.1
Conditions of computer data for the appearance ratio control and the continuation and interval controls.

Computer Data Conditions of Model B **Nov. 1993**

End items		Contents of input data		Process		
		Appearance ratio control	Continuation & interval controls	W	T	A
1	Type of floor	○		○		
2	Single sun roof W sun roof	○		○		
3	Suspended roof and sun roof	○	min. interval of 2 vehicles (sun roof) ①			○
4	Grade	○	max. continuation of 5 vehicles (H grade) ③	○		○
5	Generator	○	min. interval of 2 vehicles ④	○		○
6	Air conditioner	○				○
7	Transmission	○				○
8	4 drives	○	min. interval of 2 vehicles ②			○
9	Turbo	○				○
10	All metallic color (3 coatings)	○	max. continuation of 2 vehicles ⑤		○	
11	Interior color	○				
12	2-tone color	○			○	
13	Different lock	○				

Figures inside circles are priorities (weights).
W = welding T = trimming A = assembly

FIGURE 21.1 ***(Continued)***

line, smoothing of painting colors is unnecessary because color has no effect on the assembling of vehicles. However, in a painting line, the smoothing of colors is an important matter. Therefore, when the average appearance ratio of each item is controlled by the sequence schedule of an assembly line, weight values for each average appearance ratio of an individual spec must be considered carefully.

2. *Feasibility to implement*. Under the continuation and interval controls, the value of the maximum continuation or the minimum interval should be checked for feasibility and should be moderated in advance if necessary. The parameter should be modified automatically if the following conditions are not met in each case: add one to the maximum continuation number or subtract one from the minimum interval number.

   For continuation control:

$$N \times \frac{(E+1)}{E} \leq T$$

   where
   N = Number of vehicles concerned
   E = Maximum continued number of vehicles of the same spec
   T = Total number of all vehicles

   For the interval control:

$$\text{Number of vehicles concerned} \times \left(\begin{array}{l}\text{Min. interval}\\ \text{between vehicles}\\ \text{of the same spec}\end{array} + 1\right) \leq \text{Total number of all vehicles}$$

3. *The availability of appropriate models and the minimum appearance ratio*. If no more models are available that satisfy the rules of the continuation and interval controls, then some conditions of the continuation and interval controls should be relieved from the inferior conditions one by one. Stated differently, if the continuation and interval controls might make so strong an influence on the appearance ratio that no models could be acceptable, the overcharged influence would need to be adjusted.

When determining the *Kth* vehicle, the continuation and interval control rules suggest an answer of non-sunroof but the formula below, which suggests the attachment of a sunroof to the *Kth* vehicle, should be approved. Using a non-sunroof vehicle in the *Kth* spot would result in too large a deviation from the objective value.

$$\left|\begin{array}{l}\text{Objective value of the } K\text{'}th \text{ vehicle} \\ -\text{ Actual value of the} \left(K-1\right)\text{'}th \text{ vehicle}\end{array}\right| \geq 2.0$$

§ 2 SEQUENCE SCHEDULING USING ARTIFICIAL INTELLIGENCE

More recently at Toyota, the continuation and interval controls described in the previous sections were used at a painted body storage area between a painting process and an assembly process separately from the appearance ratio control by the goal-chasing method (see Figure 21.2). A mainframe computer in the central office determines the sequence schedule of models with different specs for the body-welding process. This allows us to realize the smoothing goal of an appearance ratio by the goal-chasing method.

Sequentially, each vehicle gets into the painting process, but here the predetermined introduction sequence is disturbed. One reason is that two-tone color cars are painted once and then returned to the start of the painting process and painted again with another color. The second reason is that defective cars are picked out of the main painting line, remedied, and returned to the line. Because of these disruptions, the sequence when all painting processes are complete will be different from the initial sequence. This altered sequence is likely to cause a line stop at an assembly process unless it is rearranged.

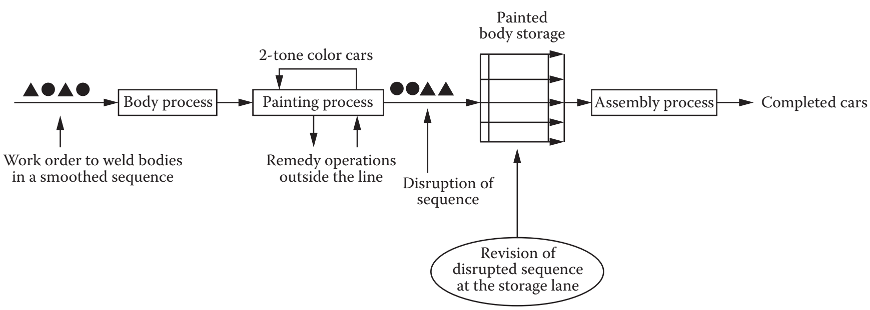


FIGURE 21.2
Introduction of various vehicles in a smoothed sequence.

The threat of line stoppages caused by altered sequences mandates the installation of painted body storage, in which cars are transposed in their sequence and delivered to the assembly line. In other words, it is necessary to transpose the sequence of cars coming out of the painting process at the painted body storage for the assembly process to achieve a smoothed workload and not cause line stops.

The painted body storage has five conveyors, and the painted cars are organized to flow in accordance to each main spec. Formerly, a well-skilled operator working at the storage exit would decide what the satisfactory sequence of jobs was, move the conveyors, and introduce them into the assembly line one by one. In the past, when a skilled operator was absent, it was difficult for even two or three section leaders working together to deal with these tasks. Now artificial intelligence (AI) performs all of these operations in the following manner.

Initially, the vehicle coming out of the painting process must be identified. Information about the vehicle, such as the ID number, specifications, and so on, is already stored in a remote ID (ID card or memory card that can be read and written on through electronic waves) attached to the body chassis during the middle of the painting process. An antenna reads this information as each vehicle enters a storage lane (see Figure 21.3).

The spec of each car in storage and its flowing sequence are recognized and transmitted to a micro-computer in the control room. The AI processing calculates the smoothed sequence of vehicles and sends its signal to the storage at the workplace, thereby moving conveyors automatically.

These sequence decisions require thought and judgment; therefore, automation in this area requires rules concerning various complex conditions and superior judgments. Also, it is the nature of the process to change: a change in production volume, changes of each spec's proportion, change of production conditions caused by improvement at an assembly process, etc., are common. For example, while the continuation control checks the maximum successive number of vehicles, this control rule is not as restrictive a constraint as the interval control that keeps the minimum interval. Which restricting rule will be applied to a particular spec of a vehicle may be altered suddenly in accordance with the change of production volume or change of a spec rate. If the alteration is managed by an ordinary computer program, it will need to be renewed each time a change occurs.

In the example above, the expert system supported by AI technology makes it possible to revise the existing program for the stated changes at

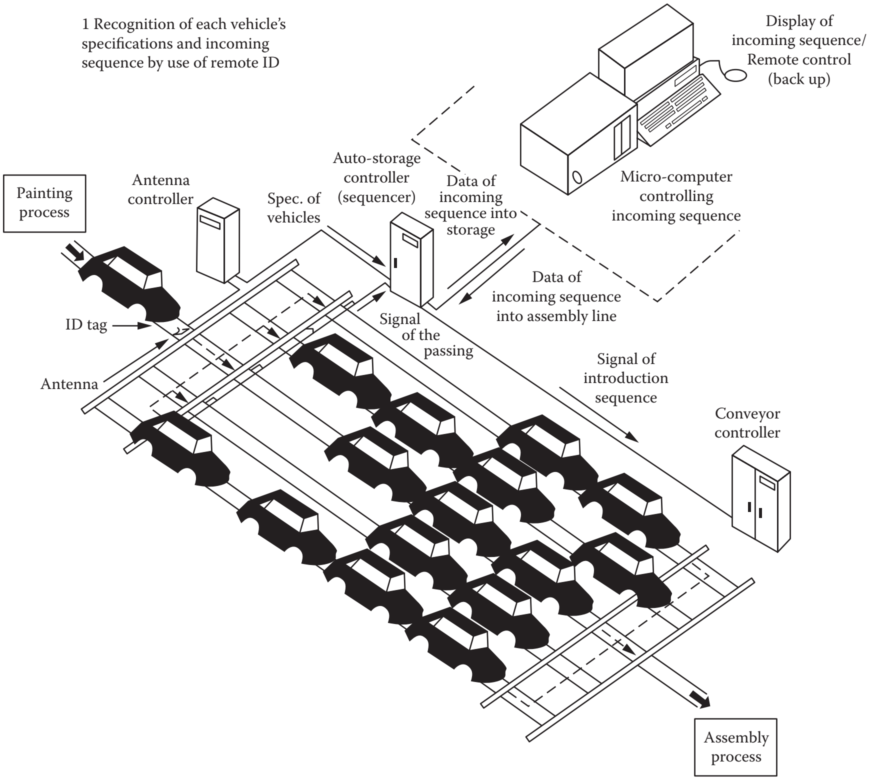


FIGURE 21.3
Smoothed sequence of vehicles by AI and FA system.

the plant. In the past, the FA System Department changed it, and plants independently managed it.

Presently, AI is a technology used to make computers perform intelligent activities, that is, to assimilate human intelligent behaviors. Intelligent activities are mainly based on the abilities to understand natural language and to infer solutions to problems.

As AI research continues, the inferring system used to solve problems has been given more emphasis relative to natural language processing. The inferring system answers problems by using the professional knowledge of experts. This inferring system is called an *expert system*.

An expert system consists of a *knowledge base* and an *inferring engine* which includes procedures of reasoning. The inferring engine will be operated by referring to data (a set of rules) stored in the knowledge base. These rules are in the form of *if, then* statements. These rules should be written so that people can easily revise them at any time. Compared with the ordinary system, the expert system has an advantage in that the structure enables easy rewrite of the set of rules without the need to revise the inferring engine's program.

The operator's way of thinking and judgment in deciding the introduction sequence of cars consists of two parts A and B, as follows. Part A is an area of knowledge that the operator will use in selecting restrictions and priority. Part B is a vehicles introduction decision procedure.

Part A can be expressed with several patterns. Because contents of these patterns are dependent on the production condition, this knowledge will be subject to revision. On the contrary, Part B is independent of production conditions and is a neutral procedure that could be applied at any time. It is the procedure of inferring itself.

Five Patterns for Deciding the Sequence Schedule

The five patterns for selecting restrictions and priorities presented here are conditions that the introduction sequence of vehicles must meet. By entering specs or values into the blanks ([*****]) in A-1 to A-5, they become customized patterns.

A-1 = "If a spec of a car is [******]
and if [max. continuation]
(or [min. interval]) is not more (or less)
than [******],
then introduce the car."

For example, if the spec of a car is [*for domestic use*] and if [*max. continuation*] is not more than [*three*], then introduce it. Also, if spec of a car is [*4WD*] and if [*min. interval*] is not less than [*four*], then introduce it, etc.

A-2 = "If number of cars being conveyed in the storage
(i.e.- stored on the way to the entrance of an
assembly line) is not less than [*****], then stop
to introduce the second car in the [*****]'th lane."

This A-2 rule is based on the following circumstance. It is difficult to introduce a car at the rear of the storage line to the assembly line. Therefore, a lane is located apart from the storage line to move the front car in a storage lane and return it to the rear. This enables the car in the rear to be introduced first to the assembly line. However, because returning takes a long time, it should not be done frequently. This is controlled by rule A-2.

A-3 = "If spec of a car is [*****]
and if a rate of inventory (in the storage) is
not less than [*****] to [******] %,
then suspend its introduction,
and if it is [*****] to [*****]%,
then introduce it,
and if it is [*****] to [*****]%,
then give it the highest priority for introduction."

Suppose a production rate of a certain spec model is 33 percent, that is, one car out of three will meet this spec. By introducing the car with spec Z first and then sequentially two cars with different specs, spec Z will flow evenly at a rate of 33 percent. Pattern A-3 is the rule that was used in this case.

A-4 = "If spec of a car is [*****],
then give the priority [*****] to it."

For example, if spec of a car is [*sunroof*], then give the priority [*I*] to it.

A-5 = "If spec of a car is [*****]
and if [max. continuation] is less than [*****],
then give the priority [*****] to it,
but if [min. interval] is not less than [*****],
then give the priority [*****] to it."

As examples for A-5, if the spec of a car is [*2WD*] and if [max. continuation] is less than [*two*], then give priority [*low*(*5*)] to it. Or if spec of a car is [4*WD*] and if [*min. interval*] is more than [*two*], then give the priority [*high*(*2*)] to it, and so on.

It is necessary to let operators know the five patterns discussed above so that they can make decisions by them. An operator in the storage area only has to put in the number of the spec and the priority in a revisions case (A-4), for example. This appears on a personal computer terminal in a spreadsheet format through the use of a knowledge editor

Registration of conditions of each vehicle

Operation Menu
[U = correction D = delete P = print E = end];

No.	Spec.	(Digit number-mark)		Comment	Priority
1	21-2	-	-	4WD	55
2	20-3	-	-	575H Wagon	10
3	44-1	-	-	ESC	50
4	26-1	-	-	Sun roof	28
5	48-2	-	-	530H	55
6	-	-	-		
7	-	-	-		
.	.	.	.		
.	.	.	.		
.	.	.	.		

Display of a computer terminal

Meaning of Knowledge of No. 1: If spec. of a car is [21-2 (4WD)], then give the priority [55] to it.

FIGURE 21.4
A knowledge editor in the form of a table.

(see Figure 21.4). As seen on the display in the figure, all the operator has to do to complete the A-4 pattern is enter the digit number mark and priority.

§ 3 DIMINISHING DIFFERENCES BETWEEN PRODUCT LEAD TIMES

In addition to the sequence scheduling solution are various other means of absorbing differences of lead time (length of process) and man-hours.

Two measures for abolishing the lead time differences are as follows:

- Prior work order—Since a two-tone color car circulates twice through a painting line, it should have priority for being introduced into the line.
- Buffer line—Cars that are out-of-order are diverted to a buffer line, placed in proper sequence, and returned to the regular line. (See Figure 21.5.)

The following are several means of absorbing differences in man-hours:

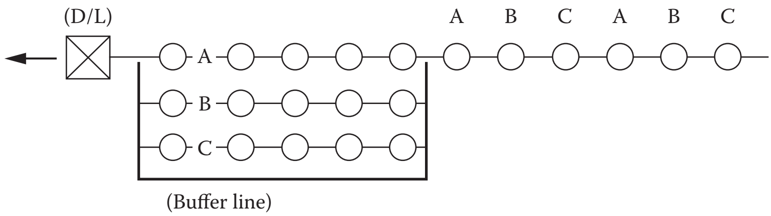


FIGURE 21.5
Buffer line.

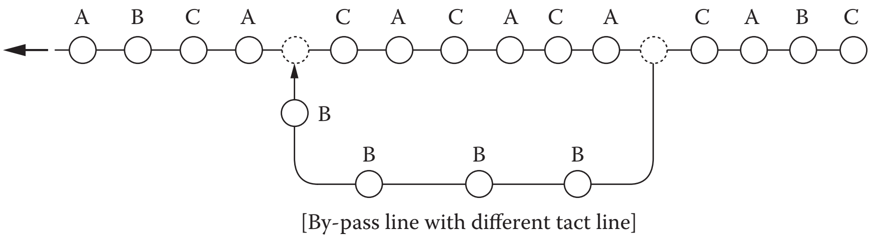


FIGURE 21.6
Installation of a bypass line.

- Bypass process—For vehicles requiring long man-hours, a bypass line is installed. These vehicles are removed from the regular line to the bypass line, which has a slower takt time. Two types of bypass lines exist. The first one is installed close to the head of the assembly line and called "former bypass." The second type is located toward the end of the assembly line and called *latter bypass* (see Figure 21.6).
- Exceptional operations—Vehicles requiring exceptional operations are handled via a subassembly line, which configures the specialized parts and then attaches them to the car while it is still in the regular assembly line. (See Figure 21.7.)
- Inside bypass (two-range usage)—Suppose a car requiring 1.1 minute of labor time is introduced into a line that has a one-minute takt range. The operator will have cut into the range for the next car when he completes the operation. Again, if the same kind of a car comes successively, he has to start the second car's assembly 0.1 minute later, thus the operation still eats into his subsequent range even further than the previous cycle. Moreover, imagine a case where the third car is the same type again. The condition will worsen as he has to start its assembly around the middle of his range, and by the time he finishes he will have used up half of the subsequent range. In such

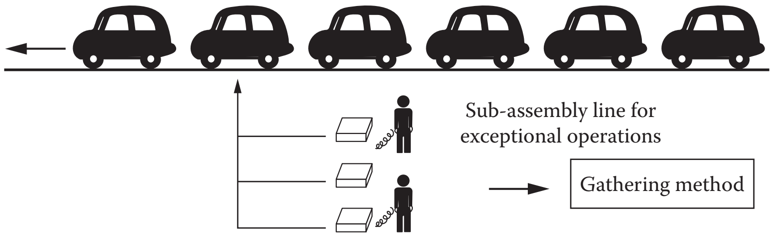


FIGURE 21.7
Exceptional operations.

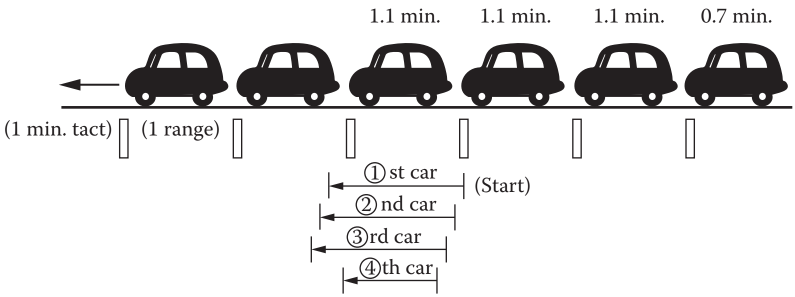


FIGURE 21.8
Inside bypass (two-range usage).

a case, if another operator is not allocated to his subsequent range, he can manage such work by using two ranges on his own. Although continuation of such cars necessarily causes a line stop, if the fourth car needs just 0.7 minutes labor time, it becomes possible to complete the assembly within the first range (see Figure 21.8).

- Exclusive use line (two-range usage)—When a car is to be equipped with a sunroof, for example, a workstation is exclusively used for attaching the sunroof. The other cars just pass through the workstation. This is another type of the two-range usage (see Figure 21.9).
- Unreserved seat—The reserved seat system is an ordinary way for specified cars to be introduced one by one in a predetermined order; it is generally used for a mixed-model line. Assembly lines, waiting lines, painting lines, and so on, have a certain number of positions for each vehicle within the line. To absorb variances in man-hours, some positions within the line can remain empty.
- Baton touch zone—Figure 21.10 shows the concept of preparing broad spaces for respective preceding and subsequent processes and intersecting them with each other. By using this method, line

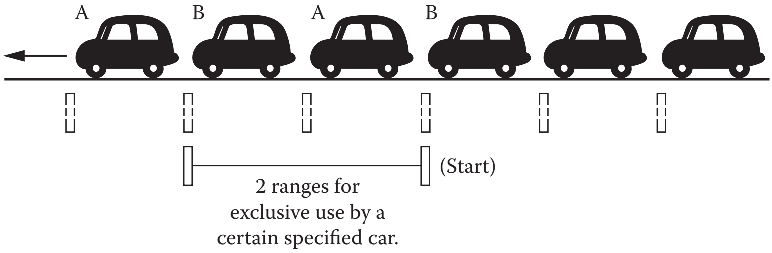


FIGURE 21.9
Exclusive use of workstations within a main line (two-range usage).

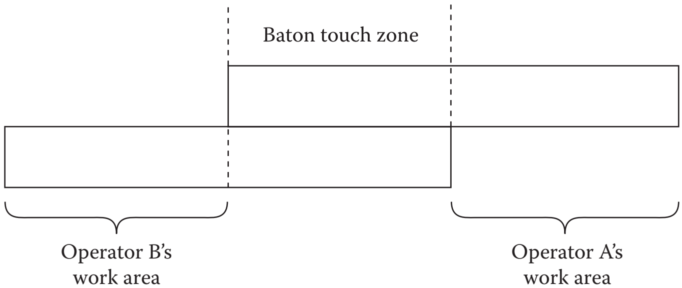


FIGURE 21.10
Baton touch zone method.

balance can be kept constant even if a difference exists in man-hours as calculated by the models. This is known as the baton touch zone method because it is similar to the zone used in a relay race for handing over a baton.

In conclusion, a countermeasure against an operational delay in an assembly line is needed to clearly signal a line stop to andon. The following are some operational causes of delay:

- Incorrect assignment of work to a process
- Operators not fully skilled
- Operation itself contains waste

After investigating these factors sufficiently, the causes of line stoppage must be eliminated. No matter what the problem is—lead time and man-hour variances, scheduling or operational delays, and so on—the causes should be identified and essential improvements should be implemented.

22

Computation of the Number of Kanban

§ 1 COMPUTATION OF THE NUMBER OF KANBAN

The kanban system as a "pull system," in which the subsequent process pulls works from the preceding process, represents either a "*constant-quantity withdrawal system*" or a "*constant-cycle withdrawal system*." In relation to inventory control, these two systems correspond to the *constant order-quantity system* and the *constant order-cycle system*, respectively; however, they may also be called the *constant-quantity production system* and the *constant-cycle production system*, respectively, when seen from the preceding process that must order the production of parts in sufficient quantities to replenish the parts withdrawn by the subsequent process.

The process for computing the number of kanban is explained in the following framework:

(1) Number of withdrawal kanban under the *constant-cycle withdrawal system*.
   (1-1) inter-process withdrawal kanban
   (1-2) supplier kanban
(2) Number of withdrawal kanban under the *constant-quantity withdrawal system*.
   (2-1) inter-process withdrawal kanban
(3) Number of production-ordering kanban under the *constant-cycle withdrawal system*.
(4) Number of production-ordering kanban under the *constant-quantity withdrawal system*.

§ 2 THE CONSTANT-CYCLE WITHDRAWAL SYSTEM FOR COMPUTING THE NUMBER OF INTER-PROCESS WITHDRAWAL KANBAN

The constant-cycle withdrawal system of inventory control will use the following formula, Equation 22.1, for determining the quantity of parts required during the total time period of order interval and production lead time:

Necessary quantity of parts =
demand quantity per day
× (order interval + production lead time)
+ safety inventory (22.1)

where the *order interval* implies the time interval between one ordering time and the next, and the *production lead time* stands for the time interval between ordering time and receiving time. The summation of *order interval* and *production lead time* is often called the *replenishment period*.

Because the *demand quantity per day* of the subsequent process appears on the right side of this equation, both order interval and production lead time are figured in days. However if *hourly demand* is used instead of *daily demand*, then both order interval and production lead time will be measured in hours.

Now, in the case of withdrawal kanban, the "order-interval + production lead time" in Equation 22.1 will be expressed by

Lead time of withdrawal kanban = Withdrawal interval
+ Production lead time

where

Withdrawal interval = Time interval between a withdrawal at time t and the next withdrawal at time $t+1$ in a constant-cycle withdrawal system

and

Production lead time = Time interval between the time the withdrawal kanban were detached at the subsequent process and then producing the number of parts that correspond to the detached kanban number in question and the time when that subsequent process has the same parts ready for use.

(This includes the time required to produce the number of parts corresponding to the detached kanban; however, if the parts were placed in the processed parts storage area at the end of preceding process, then the production time will not be included in this "production lead time.")

Therefore the *Lead time of withdrawal kanban* is the time span during which the withdrawal kanban were detached at the subsequent process and handed to the preceding process, the number of parts corresponding to the detached kanban are produced, and finally the subsequent process has the same parts available for use.

When we apply the *Lead time of withdrawal kanban* in this sense to Equation 22.1, the number of withdrawal kanban based on the constant-cycle system can be computed by the following, Equation 22.2:

Necessary number of parts during the *Lead time of withdrawal kanban*
= Lead time of withdrawal kanban
× Hourly average quantity of parts needed for the subsequent process. (22.2)

Thus,

Number of withdrawal kanban

$$= \frac{\{\text{Necessary number of parts (during the } \textit{Lead time of withdrawal kanban}\text{)} + \text{Safety inventory}\}}{\text{Capacity of one box}}$$

In case the above fraction cannot be reduced to an integer, the result should be rounded up to the next integer. If the safety inventory is less than 10 percent, then

$$\text{Safety inventory} = \text{Necessary number of parts} \times 0.1$$

Numerical Example: Number of Inter-Process Withdrawal Kanban in the Constant-Cycle System

In this example, the raw material for a certain part of the transmission first goes through the *forging process*, and then the parts are hung on the huger-conveyer and painted one by one in the painting furnace of the *painting process*. The painted parts are then processed in the *machining process* and finally assembled to the transmission in the *transmission assembly process*. The order of processes is depicted in Figure 22.1.

FIGURE 22.1
Order of transmission manufacturing processes.

The painted parts are put into parts boxes (or pallets) and stored in the *Painted parts store,* as shown in Figure 22.2. Each parts box contains a sheet of painting-ordering kanban (a type of production-ordering kanban).

To determine the number of *withdrawal kanban for painted parts,* which will be used by the machining process to receive the painted parts, we will use the following steps. (The step numbers in the following explanation correspond to the circled numbers in Figure 22.2.)

Step 1: In the entrance area of the machining line the *withdrawal kanban for painted parts* is detached, and at a designated point in time the tractor driver comes to the *painted parts storage* of the painting process to withdraw the painted parts. This withdrawal is done once every 1.5 hours. The tractor driver exchanges his *withdrawal kanban* with the *painting-ordering kanban* attached to the parts box at the painted parts storage of the painting process, and drags the painted parts boxes loaded on the tractor.

Step 2: The painting-ordering kanban that was exchanged is brought to the forged parts storage at the end of the forging process by the tractor driver of the painting process. This driver detaches the forging-ordering kanban attached to the forged parts boxes and exchanges it with his painting-ordering kanban. He then drags the forged parts boxes to the input spot of the painting furnace. This withdrawal of forged parts boxes will be made once an hour.

Step 3: The painting-ordering kanban attached to the forged parts boxes will be hung on the *production kanban hanger* on the wall of the furnace, according to the input order.

Step 4: The painting lead time in the painting furnace (i.e., the production lead time) is 3.5 hours.

Step 5: When the painting itself is finished, the painted transmission parts are stored in the painted parts storage area.

As is obvious in steps 2 and 3, the painting-ordering kanban for this painting process has not only the function of ordering painting (production order), but also the function of withdrawing the forged parts at the same time.

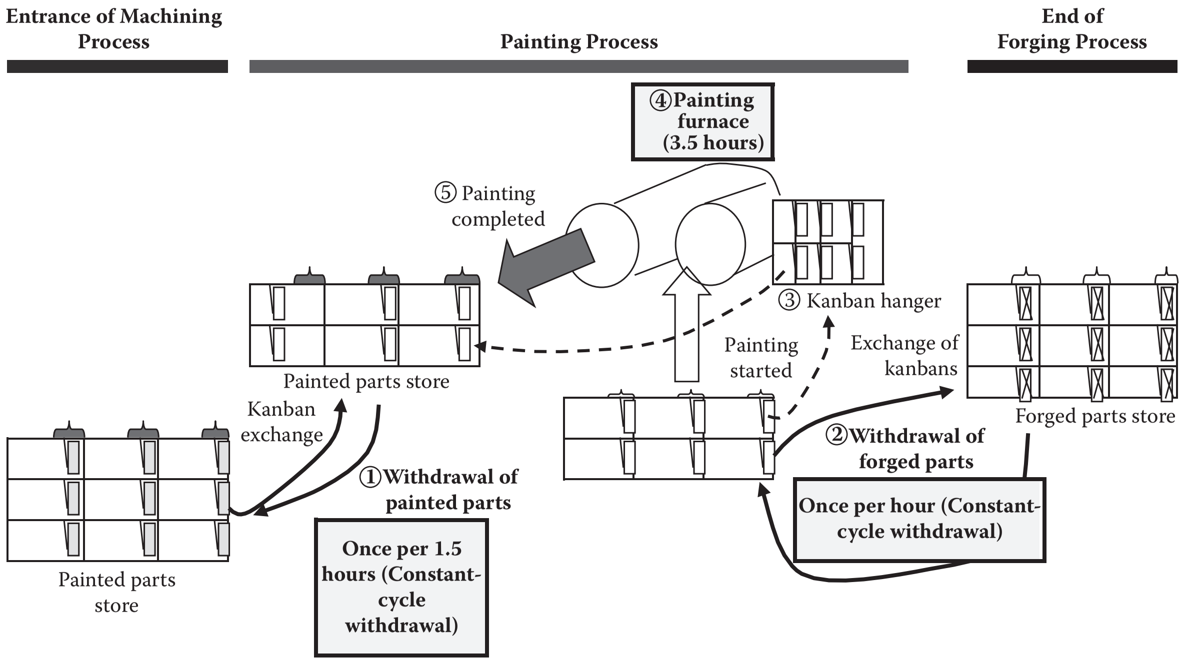


FIGURE 22.2
Movement of various kanban surrounding the painting process. (Adapted from Aoki, M. 2007. *Full Illustration of the Systems of Toyota Production Plants,* Nihon-Jitsugyou Shuppansha, pp. 19–20 with revisions.)

In this situation the necessary number of inter-process withdrawal kanban for painted parts will be computed by the following way of thinking (Aoki, 2007, p. 21 and p. 26).

"Starting from the time when a sheet of the withdrawal kanban of painted parts is detached from the machining process, to the time the painted parts come back to the same process, how many painted parts will this machining process use?" We should compute the number of kanban that correspond to this necessary number of painted parts to be used during this time span. Actually if the painted parts come back to the machining process just before the stock on hand becomes empty, we won't suffer from parts shortage.

To compute the number of withdrawal kanban of the painted parts, we need to know the *withdrawal interval* and *production lead time*.

The *withdrawal interval* from the machining process, which is the subsequent process of the painting process, is 1.5 hours.

The *production lead time* consists of 1 hour for the withdrawal interval of dragging the forged parts from the forging process *plus* 3.5 hours for the painting time in the painting furnace, for a total of 4.5 hours. The summation of the withdrawal interval and the production lead time is 6 hours.

This total of 6 hours is explained in detail as follows. Suppose the withdrawal kanban was brought to the painted parts storage of the painting process from the painted parts storage of the machining process. (Here we assume that the time spent for bringing the kanban is negligible.) Meanwhile, after the painting-ordering kanban is detached at the painting process, the forged parts are taken and painted at the painting furnace, and then the painted parts are placed in painted parts storage. Even though the painting is finished, if the tractor driver from the machining process just left the painting process you still have to wait for the next arrival of the tractor driver, at the *withdrawal interval* of 1.5 hours. This is a very important point in determining the necessary number of kanban. Adding this 1.5-hour waiting time of the withdrawal interval to the production lead time makes the total 6 hours. (If the tractor driver arrives just when the painting is finished, this 1.5-hour waiting time will not actually be spent. However, since the necessary number of kanban must be determined considering the longest possible lead time, the entire waiting time must be added.)

Further, suppose that the necessary number of painted parts per hour = 500 units, and the capacity of a parts box per one sheet of kanban = 250 units.

Then, during the 6-hour time period "*from* the time when one sheet of withdrawal kanban is detached at the painted parts storage of the machining process, *to* the time when the painted parts are brought to the same storage after painting," how many units of painted parts will be used in the machining process? This is the necessary number of painted parts units that must be stored at the painted parts storage of the machining process.

This number corresponds to the *number of withdrawal kanban for the painted parts*, and is computed by the following formula:

Necessary number of kanban

$$= \frac{(\text{Withdrawal interval} + \text{Production lead time}) \times \text{Hourly necessary units of parts}}{\text{Capacity of parts box (or units per sheet of kanban)}} \qquad (22.3)$$

where

The withdrawal interval = Withdrawal interval from the subsequent machining process.

The production lead time = Necessary time span within the self-process (painting process) + Withdrawal interval of the preceding process (forging process).

This equation is based on the idea of the constant-cycle withdrawal system" explained previously.

Therefore, applying these data to Equation 22.3:

Number of withdrawal kanban for painted parts

$$= \frac{\{1.5 \text{ hours} + (3.5 \text{ hours} + 1 \text{ hour})\} \times 500 \text{ units per hour}}{250 \text{ units per parts box}}$$

$$= 3{,}000 \text{ units} \div 250 \text{ units} = 12 \text{ sheets of kanban}$$

Hence, the total number of kanban to be utilized for the total 6 hours lead time is 12 sheets.

However, the number of kanban equivalent to the *safety inventory* should be added, in consideration of a possible parts shortage. The safety inventory is usually set at 10 percent of the necessary number of parts. The importance of reducing this amount of safety inventory through *kaizen* activities cannot be overstated.

According to the constant order-cycle system of inventory control, the quantity of units withdrawn at each withdrawal cycle varies even though the parts are withdrawn regularly. The quantity of units delivered, which is based on the number of withdrawal kanban detached, also varies each time because of the variation in actual usage of parts per hour depending on the actual production conditions in the subsequent process.

§3 COMPUTATION OF THE NUMBER OF SUPPLIER KANBAN

Supplier Kanban Using the "Constant-Cycle Withdrawal System"

Since the parts supplier is somewhat distant from the final product manufacturer, the total lead time including transportation time will be longer, and thus the product manufacturer may experience a parts shortage using the "*constant-quantity withdrawal system*." Hence the supplier kanban system uses only the "*constant-cycle (and inconstant-quantity) withdrawal system*"

Further, the total number of each supplier kanban is computed by the final product manufacturer. However, the actual number of supplier kanban transmitted to the supplier may vary depending on the actual production situation of the final product maker at each kanban delivery time.

Computation of Supplier Kanban

Returning to the basic Equation 22.1 of the constant order-cycle system, the total number of each supplier kanban will be determined by Equation 22.4, which is based on Equation 22.2:

Total number of supplier kanban = {Daily demand × (*Order interval* to the supplier + *production lead time* of the supplier) + safety inventory} / capacity of units per parts box (22.4)

For example, if the order cycle written on the supplier kanban is "1-6-2," then the parts will be delivered 6 times a day and the actual delivery of the parts designated by the number of conveyed kanban in question will be deferred by two times of kanban conveyance.

This order cycle will be expressed as *a*-*b*-*c* using the integer number of *a*, *b*, and *c*. This implies that *b* times of deliveries will be made during *a* days and each delivery will be deferred by *c* times. The *c* is called the *transportation interval* or the *delay coefficient of kanban*. The *a*-*b*-*c* is also called the *kanban cycle*. The *a* is usually just one day, and it is a special case if *a* equals more than 2 days.

Toyota requires that the number of delivery times, *b*, be increased as much as possible (i.e., frequent, small-lot deliveries), and that delivery lead times be shortened as much as possible (i.e., faster delivery or, in other words, make *c* as small as possible).

The *order interval* to the supplier in Equation 22.4 is the time span (measured by number of days) between one order to the supplier and the next, because this is based on the constant-cycle withdrawal system.

In other words, the order interval is equivalent to the time span that is needed for the product maker in two adjacent times of handing over the supplier kanban to the parts maker, and so it can be also called the *withdrawal interval* for the parts. During this time span the parts supplier will not come to deliver the parts, but the product manufacturer needs to use the parts in question during this time span. Since this order interval is *b* delivery times in *a* days, it will be calculated by Equation 22.5:

$$\text{Order interval or withdrawal interval to the parts supplier}$$

$$= \frac{a \text{ (usually equivalent to 1 day)}}{b \text{ (transportation times per day)}} \tag{22.5}$$

The measurement unit for this withdrawal interval is days. For instance, in the case of the kanban cycle "1-6-2," the right-hand side of the above equation = 1 / 6 = 0.166 days.

The "*production lead time*" of the supplier stands for the time span during which the supplier receives their supplier kanban, issues the production order to the part production line, completes the production, and delivers the parts to the product maker. (However, if the supplier has already prepared the required amount of parts and they are available in their finished parts storage, then this lead time will be shorter.) Since this time span is also dependent on the transportation interval "c," Equation 22.6 will hold:

Production lead time of supplier

$$= \text{order interval to the supplier} \times \text{transportation interval} \quad (22.6)$$
$$= (a \,/\, b)\, c$$

This transportation interval is determined mainly by the distance between the parts maker in question and the product manufacturer. The production lead time to supplier $(a/b)\,c$ is also measured in days.

We can derive the following relationship by using Equations 22.3 and 22.6:

Lead time to supplier

$$= \text{order interval to supplier} + \text{production lead time of supplier}$$
$$= (a/b) + (a/b)c = \frac{a(c+1)}{b} \quad (22.7)$$

When the supplier kanban is detached at Toyota's production line and placed in the parts delivery storage area at Toyota, it still must wait there until the next delivery truck arrives from the supplier, for the order interval time of (a/b) if the transportation truck from the supplier has just left Toyota. During this waiting time, Toyota still must be able to utilize the parts in question in their production line. In addition to the wait time for the supplier truck to arrive, there is also the production lead time of the supplier $(a/b)c$ after the supplier kanban is given to the truck driver. (See Figure 22.3.)

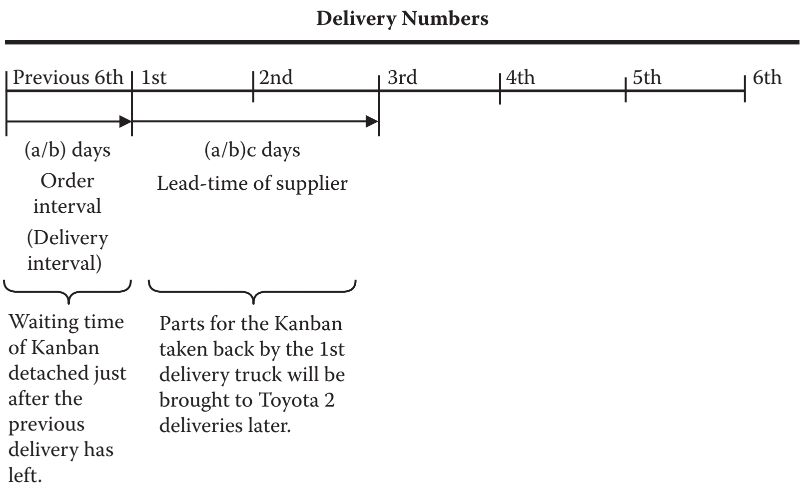


FIGURE 22.3
Supplier kanban lead time for the kanban cycle of "1-6-2."

(If the supplier truck reaches Toyota just when the supplier kanban is detached at Toyota's production line, the above order interval of 1.5 hours will not be spent. However, because the number of kanban should be computed considering the longest possible lead time, we have to add the entire waiting time of the order interval.)

The *order interval* to the supplier includes the kanban collection interval at Toyota's production site. In order for Toyota to match the timing of the regular parts-delivery from the supplier, Toyota collects supplier kanban every 40 minutes. Therefore, even though the withdrawal kanban is detached from the parts box of the line and put into the "kanban post" on the line when the first unit of parts is picked by the line-side worker early in the morning, the supplier kanban in question is not handed to the supplier immediately. Since the collection of detached kanban is made every 40 minutes, several supplier kanban and several empty boxes will usually be collected at one time.

Thus, Equation 22.4 will be re-written as follows:

Necessary number of parts during the lead time of supplier kanban
= Lead time of supplier kanban
× daily average usage of the parts in the subsequent process

$$= \frac{a(c+1)}{b} \times \text{daily average usage of the parts in the subsequent process}$$

This in turn leads to the following equation:

Total number of supplier kanban

$$= \frac{\text{Necessary number of parts (during lead time of supplier kanban)} + \text{Safety inventory}}{\text{Capacity of units per parts box}} \qquad (22.8)$$

= (daily demand / container capacity) × {(a/b)(1 + c) + safety coefficient}

Numerical Example for Computing the Number of Supplier Kanban

Now we are going to apply Equation 22.8 to the following numerical example. Suppose each variable has the following numerical data:

Number of days as a basis of transportation a = 1 day
Transportation times b during a = 6 times
Transportation interval c = 2 times after the kanban conveyance in question
Average demand per day = 100 units
Capacity of a container = 5 units
Safety coefficient = 0.2

Thus the total number of kanban will be computed according to Equation 22.8:

Total number of supplier kanban
$= (100 / 5) \times \{(1 /6) (1 + 2) + 0.2\} = 20 \times (0.5 + 0.2) = 14$ kanban sheets

§ 4 CONSTANT-QUANTITY WITHDRAWAL SYSTEM FOR COMPUTING THE NUMBER OF INTER-PROCESS WITHDRAWAL KANBAN

General Formula for the "Constant-Quantity Withdrawal System"

The constant-quantity withdrawal system is not used to withdraw outsourced parts but may be applied to withdraw in-sourced manufactured parts. On the assembly line, situations will occur in which an assembly operation may not be completed within the takt time, or defective units may be produced. The line will stop, based on the mechanism of the "autonomous defect control system" (*jidoka* or *autonomation*). In such a situation, the hourly production units vary, and when the assembly line has used *a certain quantity of parts*, they may withdraw this fixed quantity of parts from the preceding process *irregularly* (or with an *inconstant cycle*). As long as this constant quantity is smaller, the parts withdrawal can follow the variation in actual production units of the subsequent process smoothly. The basic amount of such *constant-quantity* in line-side usage at the final assembly line corresponds to *one sheet* of kanban.

Even under the "constant-quantity withdrawal system" the "*Lead time of withdrawal kanban*" is defined as the time span during which the withdrawal kanban are detached at the subsequent process and handed to the preceding process, the number of parts corresponding to the detached kanban number in question are produced, and finally the subsequent process has the same parts available for use.

This definition of "*Lead time of withdrawal kanban*" is identical to the definition given before Equation 22.2, for the "constant-cycle withdrawal system." The only difference between the two systems is that in order to compute the "kanban lead time," the "constant-quantity withdrawal system" need not consider the "*withdrawal interval*" between the time point of one withdrawal to the next, which exists only in the "constant-cycle withdrawal system."

The subsequent process needs the number of parts units to be used during this *lead time of withdrawal kanban*, and they should be stored at the line side of the preceding process. Therefore, Equation 22.2 again can hold here:

Necessary number of parts during the *Lead time of withdrawal kanban*
= Lead time of withdrawal kanban
× Hourly average quantity of parts needed for the subsequent process,

Thus,

Number of withdrawal kanban

$$= \frac{\{\text{Necessary number of parts (during lead time of supplier kanban)} + \text{Safety inventory}\}}{\text{Capacity of one box}}$$

When the *constant-quantity* in the constant-quantity withdrawal system is *more than two sheets* of kanban, the kanban lead time must be the longest lead time of the kanban in question that was first detached in the line.

Numerical Example for Computing the Number of "Inter-Process Withdrawal Kanban" Based on the Constant-Quantity Withdrawal System

Basic numerical data:

Lead time of withdrawal kanban = 20 minutes
Operating hours per day = 8 hours = 480 minutes
Average usage quantity of parts per day = 300 units
Capacity per parts box = 5 units

Therefore,

Necessary number of parts during the kanban lead time
$= 300 \text{ units} \times (20 \text{ minutes} / 480 \text{ minutes}) = 12.5 \text{ units}$

while the safety inventory = $12.5 \times 0.1 = 1.25$ units.
As a result, from Equation 22.2

Number of withdrawal kanban
$= (12.5 + 1.25) / 5 \text{ units} = 2.75 \cong 3$ kanban sheets.

Effect of Lead Time Reduction through Kaizen Activities on the Number of Kanban

In the above numerical example if we reduce the lead time to 10 minutes (keeping all other conditions unchanged) we get the following results:

Necessary number of parts to be used during the lead time
$= 300 \text{ units} \times (10 \text{ minutes} / 480 \text{ min}) = 6.25 \text{ units}$

Number of withdrawal kanban
$= (6.25 + 0.625) / 5 \text{ units} = 1.375 \cong 2$ kanban sheets.

Hence we can decrease the number of kanban by shortening the lead time through *kaizen activities*, because such kaizen can reduce the quantity of inventory necessary in the subsequent process. This effect can be seen not only in the constant-quantity withdrawal system, but also in the constant-cycle withdrawal system. The kaizen activities that are useful to reduce the lead time include "small lot production," "setup-time reduction," "defective units reduction," and so on, which are the various techniques of the Toyota Production System.

Effect of Increasing the Capacity of Parts Boxes Because of Smaller Parts Size

If we increase the capacity of parts boxes from 5 units to 10 units (keeping other conditions of the basic numerical example unchanged), we get the following results:

Number of withdrawal kanban = $(12.5 + 1.25) / 10 \text{ units} = 1.375 \cong 2$ sheets.

Thus, it obviously follows that the number of kanban decreases when the capacity of the parts box increases.

§ 5 COMPUTATION OF THE NUMBER OF PRODUCTION-ORDERING KANBAN

The *lead time of production-ordering kanban* is defined as the time interval from the time when the *production-ordering kanban* are detached at the *completed parts storage* of the process in question and the number of parts corresponding to this detached number of kanban are produced, to the time when the same process can replenish these produced parts to their completed parts storage as stock.

The number of parts needed in the *subsequent process* during the *lead time of the production-ordering kanban* will be determined by the following equation:

Necessary number of parts during the production kanban lead time
= *lead time of the production kanban*
× hourly average usage of the parts in the subsequent process.

Thus,

Number of production kanban
= {Necessary number of parts (during lead time of production kanban)
+ Safety inventory} / capacity in units per parts box.

Again, if the resulting fraction cannot be reduced to an integer, it should be rounded up to the next highest integer.

Further, if the *maximum carrying number of production kanban* to be stored at the production post (see Figure 3.11 and Figure 17.1) is more than 2 sheets, then the production kanban that was first introduced to the production kanban post must be used for measuring the *lead time of the production kanban*. In other words, the maximum lead time of the production kanban must be adopted.

Computation of the Number of Production Kanban Under the *"Constant-Cycle Withdrawal System"*

In the case of production kanban, even if the withdrawal kanban of the subsequent process is detached based on the constant-cycle withdrawal system, this regular *withdrawal interval* need not be considered. Only the time span from the time when the production kanban was detached at the completed parts storage of the preceding process to the time when the completed parts are again replenished to the same storage as a stock is important.

Applying this idea to the production kanban of the painting process, which was explained in Section 3, the *lead time of the production kanban* consists of (1) *the necessary painting time* of 3.5 hours in the painting furnace and (2) *the withdrawal interval* of 1 hour to take the forged product from the preceding process (the forging process).

Thus, if the necessary number of the parts per hour in the subsequent process = 500 units and the capacity of the parts box = 250 units, then

Number of production kanban in the painting process
= {(3.5 hours + 1 hour) × 500 units} / 250 units = 9 kanban sheets.

Computation of the Number of Production Kanban under the Constant-Quantity Withdrawal System

Suppose that a final automobile assembly line produces one completed car every 2 minutes. Accordingly, the component assembly lines, such as engine and transmission, must also produce one unit of completed product in each takt time of 2 minutes. Further, the machining process that machines these components must in turn complete one unit of processing within the 2-minute takt time. In other words, these three types of lines must be linked with an *invisible conveyer* so that they are synchronized to realize the ideal of *one-piece production*.

Actually, in the final assembly line and the component assembly lines, belt conveyers are utilized. Although the input quantity of each conveyer line is the constant-quantity of a *single unit*, irregular input can result when there is a line stoppage. Therefore, the production orders to the machining lines that are the preceding processes to the component assembly lines will also be made with the *constant-quantity and inconstant-cycle system*.

Ping-Pong Ball as a Production Kanban

As stated above, if the machining line is set up for one-piece production, following the production order of the constant-quantity and inconstant-cycle system, a ping-pong ball is often used as a production kanban (see Figure 22.4). The steps of the ping-pong ball system are as follows (Aoki, 2007, p. 25):

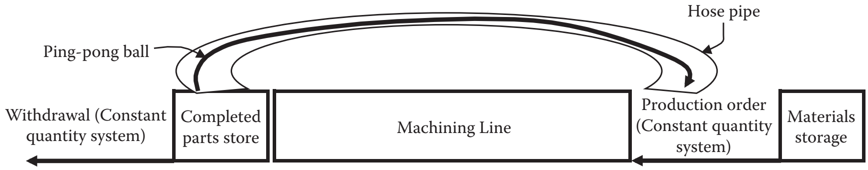


FIGURE 22.4
Ping-pong ball as production-ordering kanban. (Adapted from Aoki, 2007, p. 22, with modification.)

1. The carrier of the component assembly line will pick up one unit of a finished part from the storage at the end of the machining line.
2. At the same time this carrier will pick up the ping-pong ball specifically attached to each part in question and put it into the top (entrance) of the hose-pipe linked to the end of the machining line. The hose-pipe will hit the ping-pong ball to the starting point of the machining line by compressed air.
3. The worker at the top of the machining line will take the parts material (work) in the order of the ping-pong balls hit to him and put the work into the line.
4. The ping-pong ball placed on the corner of the work's instrument box moves with the work along the line. This movement is the same as the system for the usual production-ordering kanban because the production kanban collected at its kanban hanging board will be again attached to the completed parts boxes one by one.

Production kanban similar to ping-pong balls, such as golf balls or coin kanban (disks), have also been used.

Use of Production Kanban as a Two-Bin System

If the final assembly line often stops because of various troubles and there are frequent production delays, parts withdrawal should be made by the constant-quantity and inconstant-cycle system. Also, if the production of a subsequent process is not necessarily smoothed and the preceding process is producing in large lot sizes, then how will the production order be made? This is a situation for which the kanban system is not well suited.

If such a preceding process is the machining process, the following "production kanban post" (kanban "hanger-board") can be used for this machining process.

In the "production hanger-board" of this machining process the *maximum carrying number of production kanban* will be set for each variety of parts. If a certain kind of part uses more than two sheets of production kanban as its maximum number (in other words the production lot size is more than two boxes), then some parts may be assigned one sheet of kanban, while others may be assigned two or three sheets of kanban (see Figure 17.1 in Chapter 17).

In this case, the maximum carrying number of production kanban is the order quantity of each part in question, and at the same time this maximum number is equivalent to the parts usage quantity of the subsequent process during the lead time of the production kanban.

Here we can apply the concept of the *two-bin system* (*bin* implies a large box.) Two boxes of parts are prepared and stocked. When one box of inventory goes out of stock, the inventory of another box will be used. To replenish the empty box, an order for one box of parts will be made. In this system

Capacity of one box
= Number of units to be used in the subsequent process during the production lead time
+ Safety inventory

Also,

Capacity of one box
= Inventory quantity of the "re-order point" including safety inventory

Therefore, when one box is empty, that box will serve as one sheet of withdrawal kanban and also one sheet of production-ordering kanban. Since one empty box is also a production kanban, the capacity of one box is logically the order quantity.

Suppose we reduce the capacity of the box by half, and we have four boxes of parts inventory in the subsequent process. Suppose also that the parts production lead time in the preceding process corresponds to two boxes of parts usage in the subsequent process. In this situation, when two boxes become empty in the subsequent process and are brought to the preceding process (in other words, if two sheets of production kanban are hung on the "production kanban hanger-board"), then the parts equivalent to this two empty boxes (i.e., an order quantity of two boxes) must be produced in the preceding process.

Triangular Kanban of the Stamping Process

In the stamping process, the production lot-size is predetermined (or constant) and the production time-point will vary such that it follows the constant-quantity inconstant-cycle system. Below, we study how to determine the *re-order point* and the *lot-size*, which are used in the press process, casting process, and forging process.

§ 6 COMPUTATION OF THE RE-ORDER POINT

The signal kanban is hung on the pallet at the *re-order point* (called the *criterion number* at Toyota). When the pallet on which a signal kanban is hung is withdrawn by the subsequent process, the signal kanban is detached and then hung on the *signal kanban hanging-board*.

Now, how should we determine the inventory quantity for the re-order point? This is also determined similarly to the method for computing the number of production kanban.

The *lead time of signal kanban* is the time span from the time when the signal kanban is detached to when the completed parts became available for use in the subsequent process. Thus,

Necessary number of parts in the subsequent process
= *Lead time of signal kanban*
× Hourly average usage of parts in the subsequent process

If the safety inventory is added,

$$\text{Re-order point} = \frac{\text{Necessary number of parts in the subsequent process} + \text{Safety inventory}}{\text{Capacity of parts box}}$$

If the above fraction is not an integer, it must be rounded up to the next highest integer.

§ 7 DETERMINATION OF LOT-SIZE

The *constant-quantity* order in the constant-quantity order system of the traditional inventory control model is called the *lot-size*, which has traditionally been determined by the so-called EOQ (Economic Order Quantity) model. Using a kaizen system for the *constant-quantity withdrawal system*, the constant-quantity of production order made by the production kanban is the lot-size (except in the case of one-piece production).

However, Toyota does not determine the lot-size by applying the EOQ model. In their way of thinking, if they can reduce the setup time, they can reduce the lot-size at the same time. The lot-size is actually determined by considering the actual load in the lot-size-based production line. In other words, the lot-size should be in the range where *the total setup time per day* = total number of times of setup per day × setup time per one time of a lot-size-based production line will not exceed a *certain allowable load*. That is about 1 hour in an 8-hour day (Kotani [2008] p. 89).

When the total times of setup time per day is determined, the lot-size is determined by the following equation:

$$\text{Lot-size} = (\text{Daily average usage of parts} / \text{Times of setup per day}) + \text{Safety inventory per day}$$

Generally speaking, for parts that are used in large quantities per day, the lot-size should be as small as possible. For parts whose usage per day is smaller, the lot-size may be larger. For parts whose physical size is bigger, the lot-size should be as small as possible. For parts whose physical size is smaller, the lot-size may be somewhat larger.

§ 8 CHANGES IN THE NUMBER OF KANBAN

Changes in the number of kanban are made in accordance with changes in the estimated volume of production each month. The necessary number of kanban is calculated by a computer using the equations described in this chapter. Because it must eventually be conducted by manual labor at the production sites handling so many kanban cards, increasing the number of kanban can be very laborious work.

If the lead time is longer, the need for changing the number of kanban is likely to increase. The lead time of *supplier kanban* will be longer since outsourced parts are delivered from distant places. As a result it could be many kanban that must change their numbers. At Toyota it is said that they must change about 10,000 kanban since the assembly lines use so many kinds of outsourced parts. However, for *inter-process withdrawal kanban* used within Toyota's plants the lead time is shorter, so that changes in the number of kanban will not be so frequent. The need for changing the number of *production kanban* also depends on kanban lead time.

Changes in the Number of Supplier Kanban

First, the supplier kanban detached at Toyota's production lines are automatically sorted by the kanban sorter to identify each supplier's kanban and its number. If the number of supplier kanban should be decreased, the necessary number of kanban from each group of detached supplier kanban will be automatically subtracted by the kanban sorter.

However, if the number of kanban should be increased, it must be handled manually. The increased number of supplier kanban, including the safety inventory, must be added gradually, over (c + 1) delivery times. In other words, for a certain part the necessary additional number of kanban should be added evenly at each delivery time from the initial to the final (c + 1) delivery. For example, suppose the additional number of kanban is 15 sheets and the transportation interval (or *coefficient of delivery delay*) c is 4, then

$$15/\ (c + 1) = 15\ /\ 5 = 3$$

meaning that you can add 3 sheets of kanban to the detached kanban at each time of delivery from the first time to the (c + 1) time (Kotani, 2008, p. 91).

When it comes to reducing the number of kanban from the next month, the method is similar. The necessary number of kanban must be reduced from the detached kanban at each delivery time. If the detached number of kanban is so small that it cannot be reduced, then reduction will be deferred to the next delivery time.

When a new or changed automobile model is introduced to the assembly line, the necessary number of kanban will very quickly increase during the first several days after the model introduction. At Toyota, when a new model is launched the daily volume of the car will increase from 0 to 1,000 units within only 5 days (Kotani, 2008, p. 94). Therefore, during these 5 days Toyota must add about 10,000 different kinds of supplier kanban every day, summing up to more than 50,000 sheets of kanban.

§ 9 MAINTAINING THE NECESSARY NUMBER OF KANBAN

According to Toyota's ideal just-in-time concept, they will "produce salable product at a salable point in time in a salable quantity." This ideal implies that they will always produce by adapting to demand changes in the market, while their estimation of demand change is based on monthly demand. That is, their *master production schedule* will change monthly.

Therefore the necessary number of kanban also may change depending on changes in estimated demand for the coming month. As stated repeatedly, if the necessary number of kanban increases, the number of kanban used in the next month will be increased. If the necessary number of kanban decreases, the number of kanban will be reduced in the next month.

However, some trouble occurs if some of the actual circulating kanban are lost in the middle of the month. In such a situation if some number of kanban was subtracted out of the existing number of kanban because the computer has determined the reduced number, then there may be shortages of parts. In the next section, we consider how this problem has been solved.

Maximum and Minimum Numbers of the Parts Boxes on the Indicator Plate at the Parts Shelf

Previously, to check whether the necessary number of existing kanban sheets is being maintained, maximum and minimum stock quantities have been used at the line-side parts shelves. In other words, the *maximum and minimum numbers of parts boxes* are shown on indicator plates at each parts shelf in the production line. This is the so-called Seiton (neat placement and identification of needed work items) of the 5S movement (see Chapter 12, Figure 12.6), and is one aspect of visual management. (In reality, the total quantity of outsourced parts is not stored on the line-side shelves (see Chapter 16); *line-side shelf* here implies the parts rack in the supplier parts receiving storage.)

Maximum number of parts boxes: The stock of parts at the production site reaches the maximum level when the parts are replenished by the arrival of the delivery truck. This amount is equivalent to the lot-size of the parts in question.

Minimum number of parts boxes: Parts are consumed from the maximum stock quantity every day, and the minimum level occurs just before the next delivery comes in from the supplier. Therefore, this minimum level of stock is safety inventory.

If the actual level of inventory on the shelf falls below the minimum level, it means that the number of kanban was reduced on account of *being lost,* et cetera. On the other hand, if the actual level of inventory on the shelf exceeds the maximum level written on the indicator plate, then it means somebody has added unnecessary kanban.

In this way the *indicator plate* has been useful for introducing the kanban system. However, because there are thousands of parts in stock, it would be very laborious and beyond the manpower of team leaders in the plant to monitor the differences from maximum and minimum levels of parts boxes and to correct the actual number of kanban on the plant shelves.

Thus, the *automatic pushing-aside system of the inflated kanban* was developed as a personal computer system.

Automatic System for Pushing Aside Excess Kanban

This system can be applied to both conventional supplier kanban and electronic kanban based on the conventional method (i.e., *one-way* kanban). Thus, only its essence will be described here (Aoki, 2007, pp. 72–76.).

Step 1: The necessary number of supplier kanban for each supplier in a given month must be registered in the kanban reader (or kanban sorter) at Toyota.

Step 2: Whenever the supplier kanban for a part goes through the kanban reader, the series number must be attached and stored with the kanban in question (or unique serial figures will be attached to all kanban of the supplier in question), and also stored in the kanban reader as well.

Step 3: If the FIFO (First-In, First-Out) method is applied well when parts are consumed, and the detached kanban go through the kanban reader, the kanban whose serial number is stored will pass through the reader until the series number reaches the necessary number of kanban, and any kanban exceeding the required number will be automatically pushed aside.

Since unnecessary kanban can be automatically kicked out using this system, nobody needs to handle the reduction process when the necessary number of kanban is reduced.

Discovery of Lost Kanban

When one day has passed since the necessary number of kanban for a certain month has been registered, the serial numbered kanban have passed through the kanban reader. If we find that some parts are not satisfying the necessary number of kanban, then additional kanban must be introduced, because this must be due to some lost kanban.

23

New Developments in e-Kanban

§ 1 THE TWO TYPES OF E-KANBAN

The term *e-kanban* refers to the method Toyota uses to order parts from its suppliers, whereby Toyota does not pass any kanban cards to the handlers responsible for moving the parts, but uses information technology to send order information to the parts manufacturers electronically.

Two types of e-kanban are used: one (called *earlier-replenishment e-kanban*) is a method relating to the sequenced withdrawal of parts in accordance with the final vehicle loading sequence schedule; the other (called *later-replenishment e-kanban*) is the conventional outsourcing kanban method. The two types of kanban are explained below.

§ 2 SEQUENCED WITHDRAWAL METHOD E-KANBAN: SEQUENCED WITHDRAWAL OF PARTS MATCHED TO THE VEHICLE LOADING SEQUENCE SCHEDULE

The Evolution of the Kanban

From around 1950, when Taiichi Ohno first devised the kanban system, until around 1974, Toyota used kanban to “pull” large parts like engines and transmissions as well as smaller parts. However, using kanban to pull engines and other large parts meant that every type of such parts had to be ready and waiting in the supplier’s finished-goods storage area, taking up a lot of space.

For this reason, around 1975, Toyota decided to restrict the use of kanban to pulling large parts like engines (by the *later-replenishment system*) to factories located far away from the final assembly line.

Meanwhile, the company stopped using kanban to pull engines from neighboring engine factories. Instead, it began to use the sequenced withdrawal method, sending the required engine sequence information (matching the information from the sequence schedule for introducing the different vehicle models onto the main lines) every day by computer to these factories.

However, this type of sequenced withdrawal was also problematic because it meant that the engine factories' production managers had to keep in constant contact with the vehicle lines' production managers in order to find out the actual state of progress of the vehicles. This was very time-consuming.

For this reason, around 1998, Toyota decided to put the vehicle sequence information directly onto a kanban and send that kanban information, without passing through anyone's hands, electronically to the factories where the engines and other large parts were produced (see Figure 23.1).

e-Kanban

Generally speaking, in the MRP philosophy, if the MRP *time bucket* (the minimum production period unit) is split up into hours and then further into minutes, and if the vehicle sequence and timing are known, then it should be possible to compute the necessary numbers and timings of the parts required for each vehicle model. When the necessary numbers of all the parts required at each time have been calculated, assuming that the number of parts and deliveries per kanban are decided in advance, it is possible to calculate the number of kanban and the delivery timings required momentarily each day. This constitutes the e-kanban for the sequenced withdrawal system of the vehicle main line.

The order in which the vehicle models are introduced onto the vehicle main line (the loading sequence) is confirmed three days before vehicle completion. (In the past, the vehicle model loading sequence schedule could only be confirmed two days before the roll-off day, but it can now be confirmed a day sooner.) Having three days' lead time to process the information makes it possible to issue e-kanban for all the parts and get them delivered before the previous ones are used up. In other words, the engines that are about to be used can be lined up in order beside the vehicle assembly line, ready for use as soon as they are needed.

Emphasizing the point that the parts are delivered before the previous ones have been used, this system is called *earlier-replenishment e-kanban*

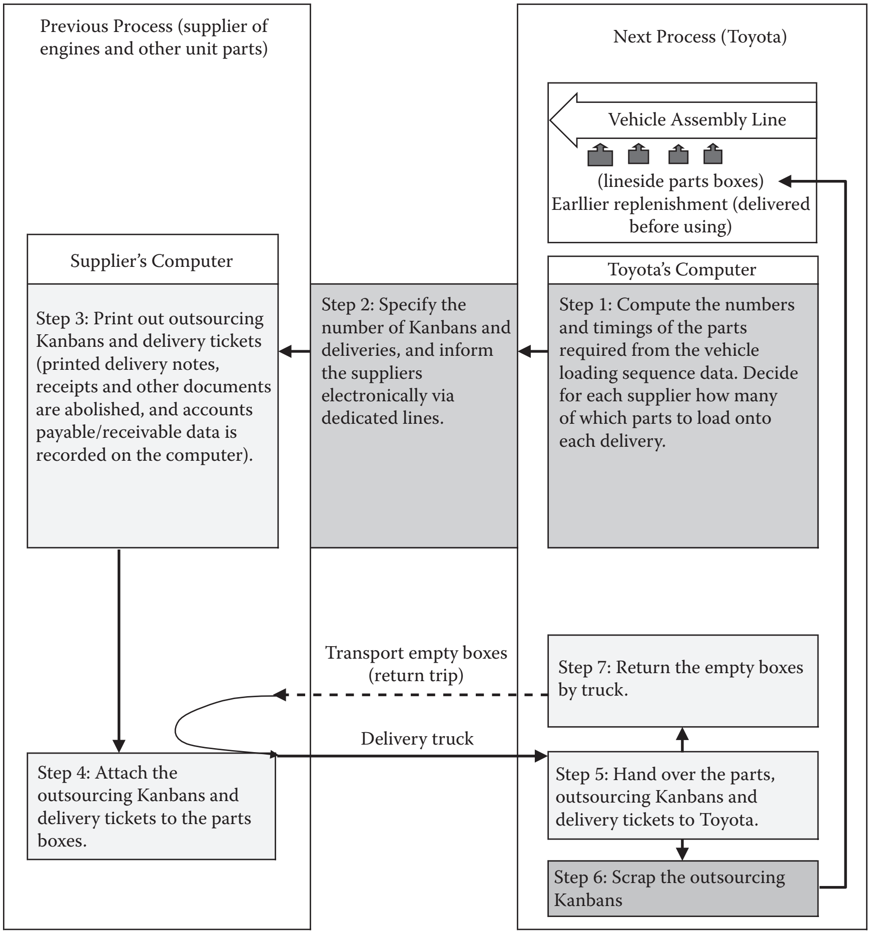


FIGURE 23.1
The e-kanban mechanism in the earlier-replenishment (sequenced-withdrawal) system.

or *advance delivery e-kanban*. These earlier-replenishment e-kanban are also just called *e-kanban* in distinction from the later-replenishment e-kanban described below (Kotani, 2008).

However, since there are only about two or three hours between the order coming from the vehicle line and the time when the part will be used, this system can only be used for large functional parts, typically transmissions, engines, accelerators, tires, seats, and bumpers.

Since the deliveries made in accordance with these e-kanban follow the vehicle loading sequence schedule, naturally smoothing the hourly parts usage, there are few changes to the daily delivery quantities, and "fixed-time, fixed quantity delivery" can be said to have been achieved.

§ 3 E-KANBAN IN THE LATER-REPLENISHMENT SYSTEM: E-KANBAN FOR THE PARTS NEEDED ON ENGINE ASSEMBLY LINES, AND SO ON

Assembly lines for engines, and so on, are classified as large engine lines, medium-sized engine lines, and small engine lines, with their products destined for large, medium-sized, and small vehicles respectively; but all engine lines also receive orders from a range of different vehicle factories.

Each engine line groups together its orders from a number of vehicle factories and introduces the necessary smoothing conditions (e.g., "appearance ratio control rules," "continuous/interval control rules," etc.; see Chapter 21), and decides on the engine assembly sequence so that the use of all the parts is spread out, rather than being concentrated on any particular part. It then orders the parts on this basis.

The difference between an engine assembly line and a vehicle assembly line in this respect is that, while in MRP terms a vehicle is a final consumer product and is therefore a so-called "independent demand item" (or a "basic production planning item"), an engine or a transmission is a "dependent demand item," produced in accordance with orders from various vehicle factories.

This means that it is difficult to finalize the number of engines to order until just before starting the work. Because of this, while the vehicle loading sequence schedule can be drawn up three days before vehicle completion, the engine sequence schedule cannot be drawn up until the day before engine completion. This means that there is insufficient data processing lead time to issue electronic kanban enabling the sequenced withdrawal of the parts required for engine assembly based on the engine sequence information.

A special type of electronic kanban (the *later-replenishment e-kanban*) similar to a conventional kanban was therefore developed for the parts used in engines, transmissions, and so on (see Figure 23.2). The procedure for using later-replenishment e-kanban is as follows:

Step 1: As an operator on the engine assembly line uses up a particular part, he or she detaches the supplier kanban from the parts box and places it in the kanban post.

Step 2: The line leader periodically collects the kanban that have accumulated in the kanban post.

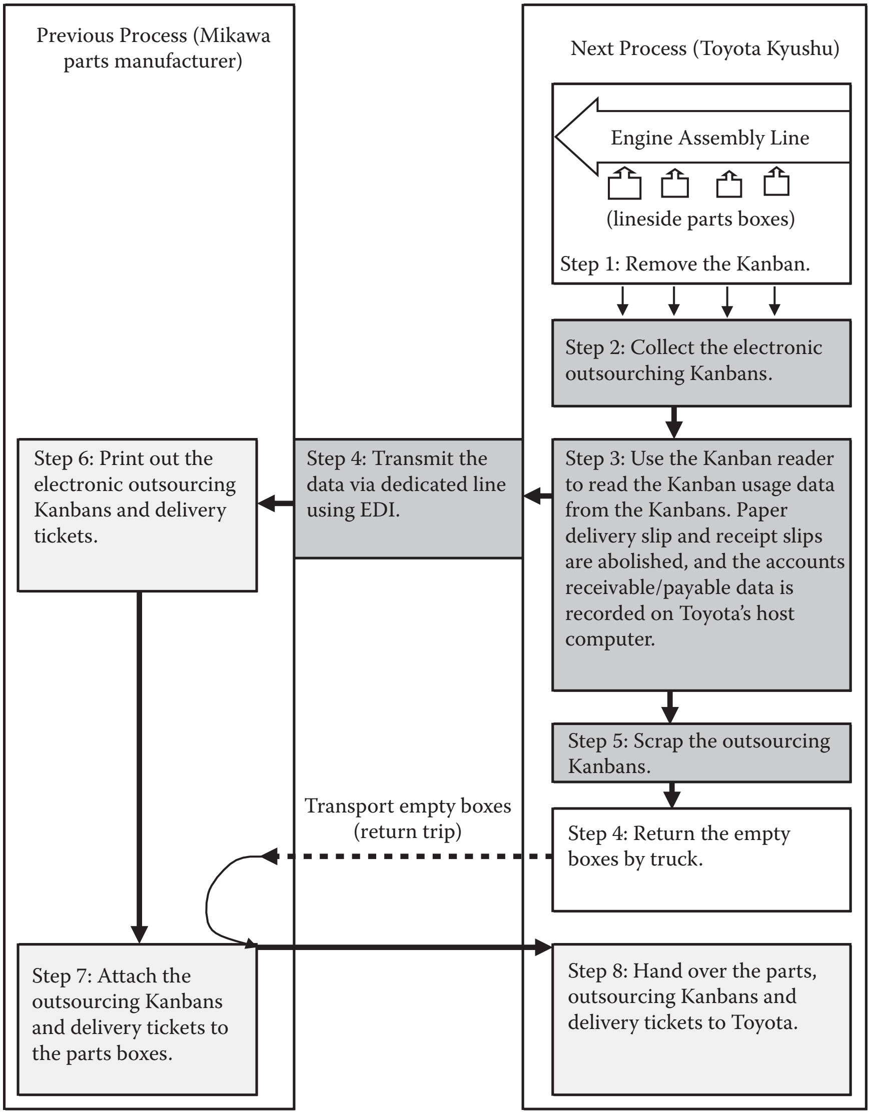


FIGURE 23.2
The e-kanban mechanism in the later-replenishment system.

Step 3: The collected detached kanban (these have barcodes on them, so they are e-kanban) are read by a kanban reader (a barcode reader).

Step 4: The data read by the barcode reader (parts names, number of kanban used, quantity of parts used, etc.) is sent via an EDI (electronic data interchange) system through dedicated lines to Toyota's parts factories and outside parts suppliers.

Step 5: The kanban read by the barcode reader are scrapped.
Step 6: Paper kanban (also e-kanban) and delivery tickets are printed out at the parts factories receiving the data.
Step 7: The drivers deliver the completed parts that are waiting at the parts factories to Toyota, together with their associated kanban and one copy of the delivery ticket for the parts delivered.

The e-kanban in this later-replenishment system were developed because parts factories located far from the vehicle assembly factory found it impossible to keep up when using the original method (in which someone from the parts manufacturer or supply depot had to go to the assembly factory, collect the kanban, and attach them to the products to be delivered).

However, even parts manufacturers not far from the vehicle assembly plant have switched from conventional kanban to e-kanban if they are able to handle network communications data. In this sense, all of Toyota's kanban can be said to be heading in the direction of converting to their electronic form (see Figure 23.3 for an example of this kind of e-kanban).

§ 4 SEQUENCE INFORMATION FOR MAIN, UNIT, AND SUB-LINES

A *unit assembly line* is an integrated factory where the materials for large parts such as engines and transmissions are machined, assembled, and finished.

The many vehicle assembly lines, which are such factories' next processes, are geographically dispersed. The completed transmissions and engines have to be supplied to these various lines.

Thus, although the completed transmissions and engines have to be supplied in accordance with the vehicle loading sequence for each of the individual vehicle assembly lines for which they are bound, the unit assembly line itself has to assemble the units in its own loading sequence, governed by smoothing conditions different from those on the vehicle assembly lines.

The loading sequence information for the unit assembly lines is definitely not streamed to their own sub-lines (e.g., the piston machining lines, boring lines, and other sub-lines feeding an engine assembly line). This is because the sequence of the main vehicle assembly lines and unit assembly lines sometimes changes as a result of defectives being produced, or for other reasons. If this happened and the sub-lines had been processing

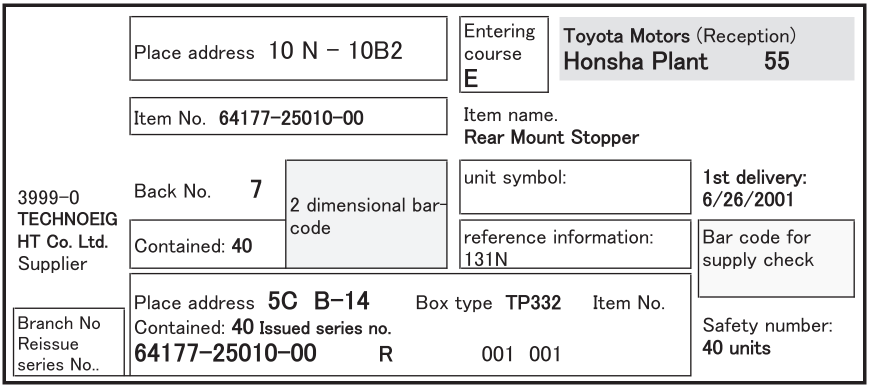


FIGURE 23.3
Sample of electronic kanban for later replenishment. (Adapted from Kotani, 2008, p.72.)

parts in a predetermined sequence, the parts from the sub-lines would then be supplied to the unit assembly lines in the wrong order and the sub-lines would create unnecessary inventory.

So, how is the required production sequence on the sub-lines communicated? The method used is to display pictures of the actual units being assembled on the unit assembly lines, in the order in which they are being assembled, on monitors next to the sub-lines. The sub-line operators watch the monitor screens and check the sequence visually.

For example, on a piston machining line constituting one of the sub-lines for an engine assembly line, the monitor screens show numbers indicating the piston diameters that are stamped on the engine blocks being passed down the engine assembly line. These pictures are taken with cameras installed above the engine assembly line and are sent to the monitors.

The relationship between the sequence schedules for the vehicle assembly lines and for the unit assembly lines and their sub-lines is shown in Figure 23.4.

The crucial difference between the e-kanban in the earlier-replenishment system and the later-replenishment system is that, in the former system, kanban removed at the final assembly line are not used as information for withdrawing parts; instead, e-kanban are generated at the parts manufacturers using the information on the vehicle loading sequence schedule (i.e., the advance production order information for the vehicle assembly line), finalized on the basis of the orders received from the vehicles' sales dealers.

Nevertheless, since the earlier-replenishment e-kanban are also read by the kanban reader at Toyota to check for any discrepancies between the

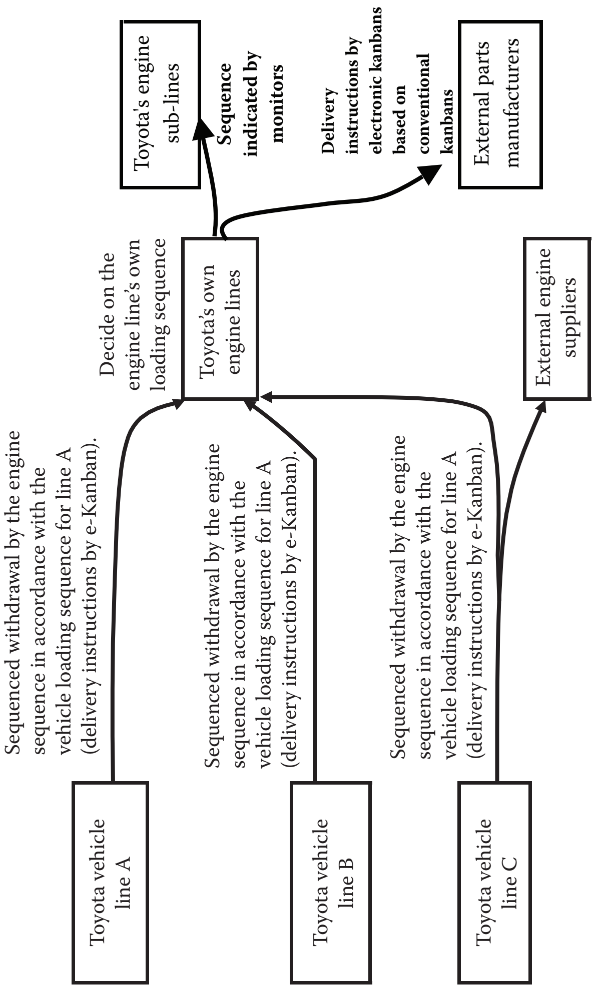


FIGURE 23.4
Sequence information on the main, unit, and sub-lines.

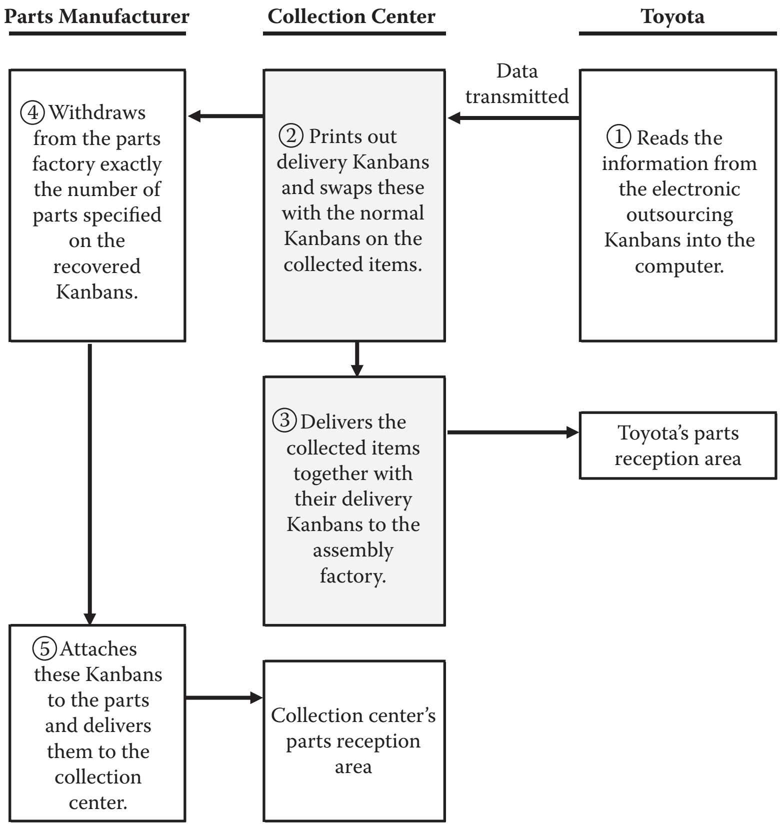


FIGURE 23.5
e-Kanban passing through a collection center.

planned and actual quantities of parts used on the assembly lines and process the accounts payable and receivable, there is no apparent difference between these and the later-replenishment type of e-kanban.

§ 5 E-KANBAN PASSING THROUGH A COLLECTION CENTER (AN INTERMEDIATE WAREHOUSE)

In an increasing number of instances, parts manufacturers located far away from an assembly manufacturer do not deliver the parts directly to the assembly manufacturer but to a “collection center” (an intermediate warehouse) close to the assembly manufacturer. The intermediate warehouse delivers mixed loads of parts from various different parts manufacturers to the assembly manufacturer. This type of delivery is called *delivery via a collection center* or *cross-dock delivery*.

The system works following the four steps as shown (see Figure 23.5).

24

Kanban Supporting Information Systems

§ 1 TOYOTA PRODUCTION SYSTEM IS SUPPORTED BY MANY INFORMATION SYSTEMS

Through lack of understanding, the Toyota Production System is sometimes considered far removed from modern computerized information systems. Moreover, it is felt that just-in-time (JIT) production can be realized only by the kanban pull system. However, before applying kanban, detailed schedules must be prepared in advance for each production process using monthly planning data. This scheduling is accomplished by a computerized information system.

Toyota production is supported by various computer-based systems as discussed in Chapters 6, 20, 21, 22, and 23. Another example in this chapter is based primarily on systems of Toyota, Kyoho-Seisakusho Company, Ltd., and Aisin-Seiki Company, Ltd. However, since companies of the Toyota group are closely aligned with the Toyota Motor Corporation, similar systems are used among many suppliers as well.

The computerized information system reported herein consists of seven subsystems that may be classified roughly into three categories (Figure 24.1):

1. *Technology database* subsystem, which maintains the database for the planning and actual performance subsystems
2. *Planning* subsystem, which provides plant managers with information for preparing production arrangements for the next month, such as determining the number of kanban and the distribution of workers on the assembly line
3. *Actual performance* subsystem, which supplies information that directs attention to improving processes by comparing actual performance with planned data

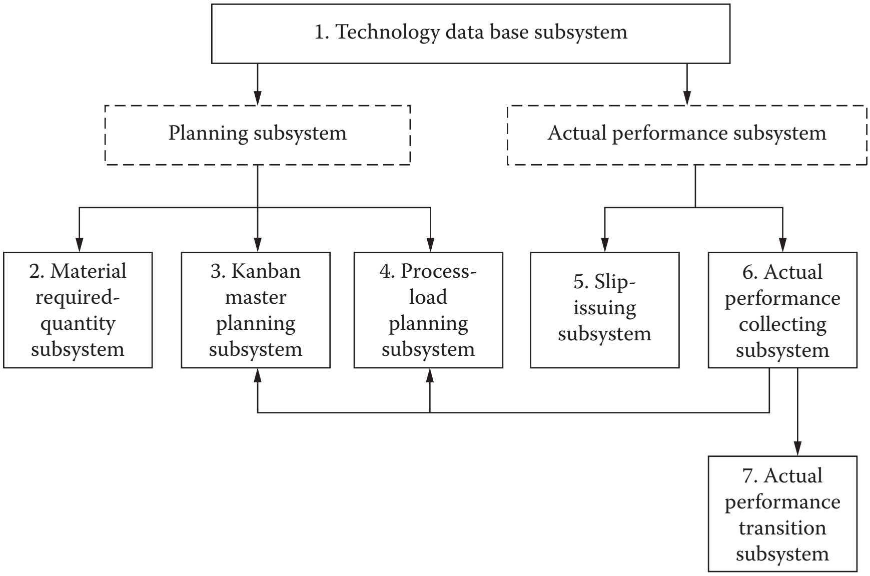


FIGURE 24.1
Framework of the information system supporting kanban.

These subsystems will be examined in the following sections.

The technology database subsystem maintains the basic data for production controls. It includes a parts database (bill of materials) to compute the various parts quantities required for each finished product and a collection of data to reflect the steps in producing a company's products from beginning to end.

Kyoho-Seisakusho Company, Ltd. has been using a UNIS database (UNIVAC Industrial System) with software developed by Japan UNIVAC Company, Ltd., for this subsystem. This UNIS was originally developed for MRP. In this sense, the kanban system is compatible with MRP.

§ 2 MATERIAL REQUIREMENT PLANNING SUBSYSTEM

This supplier subsystem receives predetermined three-month production information as input data provided monthly by Toyota to its cooperative parts suppliers. The subsystem then computes the quantity of material required by each process, based on their "bill of materials" database. The outputs of this system are summarized as follows:

- Daily required quantities of each material to be used within the company or by its suppliers
- Number of pallets to contain each material
- Production schedule of each finished product to be supplied to each customer company

To accomplish JIT production, daily required materials must be prepared in advance to be available at any necessary point in time. Also, in accordance with Rule 3 of the kanban system: "defective units should never be conveyed to the subsequent process." The defective rate cannot be considered in computing the required material quantities. The Toyota Production System consists of not only the kanban information system but also the production methods to improve the process when defective units are discovered.

The car development department has centrally managed Toyota's bill of materials system, called SMS (Specifications Management System), and has integrated various operations of the company in a harmonized way. This is another main operations information system comparable to the TNS discussed in Chapter 6. It was prepared in 1982 and is still widely used with various refinements within Toyota's group companies (see Figure 24.2). In 2003 this system was renewed as the "New SMS," to be utilized by globally

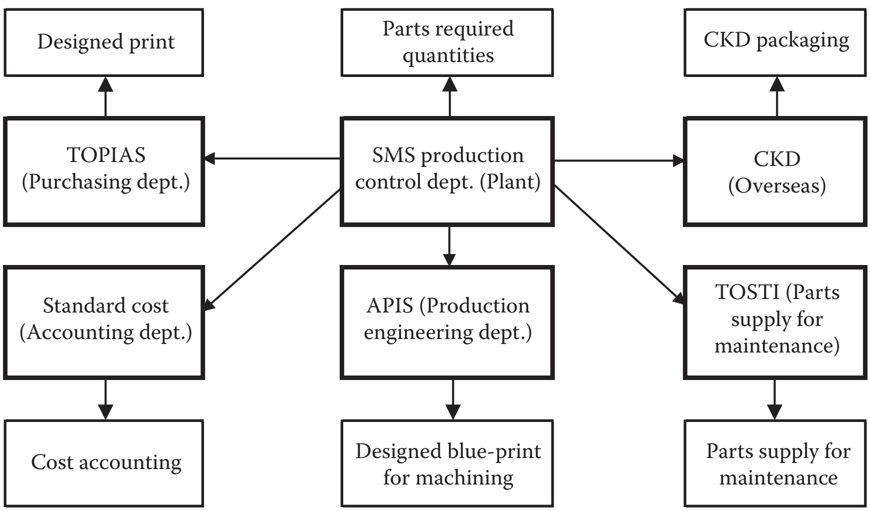


FIGURE 24.2
Toyota SMS (Specifications Management System). (Adapted from Toda, M. 2006, p. 36.)

located companies and in all operations. The new SMS is also called the "global integrated BOM database." In addition, various operational applications are being developed using this new SMS as a core system.

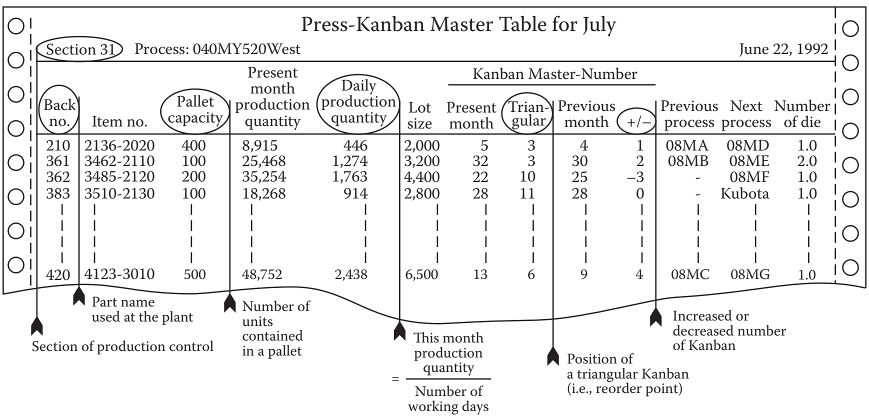
§ 3 KANBAN MASTER PLANNING SUBSYSTEM

The kanban master planning subsystem computes the following data based on a daily leveled (average) production quantity:

- Number of each kanban required for producing a lot
- Increased or decreased number of each kanban compared with the previous month
- Position of a triangle kanban (which corresponds to a reorder point and triggers production timing)
- Lot size

This data will be printed out as a *kanban master table*, as shown in Figure 24.3. The table is delivered to the manager of each process for preparation of the actual number of kanban. Further, since the daily average production quantity changes basically once a month, the data must be recomputed monthly.

Three different kinds of kanban master tables are used, depending on the following application.


Press-Kanban Master Table for July

Section 31 Process: 040MY520West June 22, 1992

Back no.	Item no.	Pallet capacity	Present month production quantity	Daily production quantity	Lot size	Kanban Master-Number: Present month	Triangular	Previous month	+/−	Previous process	Next process	Number of die
210	2136-2020	400	8,915	446	2,000	5	3	4	1	08MA	08MD	1.0
361	3462-2110	100	25,468	1,274	3,200	32	3	30	2	08MB	08ME	2.0
362	3485-2120	200	35,254	1,763	4,400	22	10	25	−3	-	08MF	1.0
383	3510-2130	100	18,268	914	2,800	28	11	28	0	-	Kubota	1.0
420	4123-3010	500	48,752	2,438	6,500	13	6	9	4	08MC	08MG	1.0

FIGURE 24.3
Kanban master table.

Internally Produced Parts

This table is printed out for each part/item at each process. The table is delivered to the production control department for preparation of kanban and reorganization of each process (i.e., reallocation of workers) in response to demand changes. The formulae used at some suppliers follow:

$$\text{Lot size} = \frac{\text{Monthly production quantity of particular product}}{\text{Monthly setup times for particular product}} \tag{24.1}$$

$$\text{Number of kanban per lot} = \frac{\text{Lot size}}{\text{Pallet capacity}} \tag{24.2}$$

$$\text{Position of triangular kanban} = \frac{\text{Daily average production quantity}}{\text{Pallet capacity}} + 1 \tag{24.3}$$

Detailed information is available for the above formulae in Chapter 22.

Externally Produced Parts

This table is printed out for each supplier and each kanban cycle so that each supplier will know the monthly change in their required production quantities. The formulae used to compute the number of supplier kanban are different from the equations for internal kanban because a constant-cycle withdrawal system is applied to the supplier kanban while a constant-quantity withdrawal system is normally applied to internal kanban. More detailed information and the kanban cycle concept appear in Chapter 22.

Material Usage

This table is printed out for delivery to the material supplier. For example, if a punch press process is involved, the number of kanban for a coil lot will be sent to the coil supplier.

§ 4 PROCESS-LOAD PLANNING SUBSYSTEM

Monthly production quantities fluctuate depending on the predetermined production plan published monthly by Toyota. Thus, each production line must be able to adapt to these monthly changes in production quantity by changing the capacity of each line, that is, by increasing or decreasing the workforce at each line. Such changes can be attained through improvement activities or multi-function workers in a special layout of machines.

In order for each process to impact the workforce capacity change, this subsystem computes the following data into a *process-load plan* based on the monthly predetermined production plan:

- Cycle time at each process
- Processing time or loading time to be spent for a given lot at each process
- Setup time and the times of setup at each process

By comparing loading time to the existing capacity at each process, a series of production preparations such as workforce planning, machinery layout, and overtime planning can be calculated. The process-load plan reflects data generated for the kanban master plan and required material quantities. Thus, if the load at a process changes, the workforce or number of kanban changes accordingly. The following formula is used to compute loading time spent for a given production lot:

$$\text{Loading time} = \frac{\text{Order quantity} \times \text{Standard hour}}{\text{Standard quantity} \times \text{Process utilization rate}} + \text{Setup time} \qquad (24.4)$$

The standard quantity and the standard hour are usually predetermined at each process. For example, assume an order quantity (lot size) of 100 units, standard hour equal to one hour to produce ten units of standard quantity, and the setup time of two hours. Then, the loading time for this process is computed as

$$\frac{100 \times 1}{10} + 2 = 12\,\text{hours}$$

In the case of a punch press department, "strokes per hour" (SPH) is substituted for "standard quantity times process utilization rate," as noted here:

$$\text{Loading time} = \frac{\text{Order quantity} + \text{Quantity produced by one pressing}}{\text{SPH}} + \text{Setup time} \tag{24.5}$$

where SPH and setup time are computed based on data from the past three months as collected by the *Actual Performance* subsystem. Additionally, cycle time will be used to standardize the operations routine and to determine the standard quantity of in-process inventory.

§ 5 ACCOUNTS PAYABLE AND ACCOUNTS RECEIVABLE SUBSYSTEM VIA ELECTRONIC KANBAN

Kanban may be regarded as a kind of currency because when a process withdraws a part from the previous process, a withdrawal kanban must be shown in the part-making process. However, a kanban specifies only what type of part is required, where the part must be transferred to and from, and the quantity of parts to be produced until what time. The *transfer price* is not defined by the kanban, whereas the price and monetary information are necessary between a supplier and a user company. Therefore, to deal with accounts payable and accounts receivable in the accounting departments of both companies, some invoices must be issued. Such invoices are also used to confirm and inspect the total quantity of the item supplied by the vendor.

As described in Chapter 4, Toyota applies two different systems to withdraw parts from various suppliers, depending on the physical size of the part. The most prevalent system is the *later-replenishment* system, which uses a supplier kanban. The second system is the *sequenced withdrawal* system based on a sequence schedule for the mixed-parts assembly line. The following describes the new accounting system used to pay for the purchase of parts delivered by means of kanban system.

Because the date read by Toyota's kanban reader is recorded on Toyota's host computer, the delivery notes, receipts, sales dockets, and other paper documents that used to be printed out by the supplier for verification are now completely unnecessary. This was done because of the need to go paperless with these kinds of forms. However, most of the accounts payable/receivable data on outsourced parts (the data on Toyota's accounts payable and the parts manufacturers' accounts receivable) is recorded on Toyota's host computer.

Also, the relevant monetary amounts are ultimately confirmed by means of the *delivery tickets* (a *delivery ticket* is a kind of delivery note forming a pair with an electronic kanban) relating to the parts actually delivered by the parts manufacturers. If a parts manufacturer cannot deliver exactly the right numbers of a particular part as specified electronically in Step 4 above, the numbers are made up on a later delivery, accompanied by a *split ticket*.

Since all the data relating to accounts payable and receivable is also processed on Toyota's computer, documents such as delivery notes and receipts have been scrapped for both the earlier-replenishment e-kanban and the later-replenishment e-kanban. Even in the earlier-replenishment e-kanban system, the parts manufacturers hand over electronic kanban and delivery tickets to Toyota together with the parts they deliver.

Until these electronic kanban methods were adopted, delivery notes and receipts were printed out when the outsourcing kanban were read in by the parts manufacturers' kanban readers upon receipt, and these were brought in to Toyota together with the parts. The delivery notes were read by Toyota's OCR (optical character readers) and the data recorded as accounts payable data on Toyota's computer. The receipts were stamped by Toyota and taken back to the parts manufacturers by the truck drivers, where they were read by the parts manufacturers' OCRs and recorded as accounts receivable data on the parts manufacturers' computers. Toyota and the parts manufacturers then compared their respective accounts payable and receivable data at the end of every month. If a parts manufacturer's data showed that it was owed more than Toyota thought it was, the parts manufacturer was obliged to present its receipts to Toyota to verify its claim, and it used to take a long time for the parts manufacturer to find all the necessary receipts, creating a bottleneck in the kanban process. This problem has now been solved.

§ 6 ACTUAL PERFORMANCE MEASUREMENT SUBSYSTEM

The *Actual Performance Collection* subsystem daily collects the actual performance data of each process and compiles it as monthly production information. The performance data includes production quantity, processing time, setup time, cycle time, machine idle time, stroke number, etc. Monthly production data is included in the monthly planning cycle. Comparing actual performance data to the planned figures produces variance figures. If these variances are unfavorable (i.e., processing too slow), some remedial action must be taken to minimize the variances. In other words, this subsystem highlights problem areas and helps to evoke improvement activities to optimize Toyota production methods. Additionally, actual performance data, such as stroke number and setup time, are fed back as basic data for computation of the loading or cycle time for the next period.

The *Actual Performance Transition* subsystem transforms the actual performance data into time-series data of the latest three months to show the progress of actual performance. This time-series information emphasizes the technical differences between processes and the capacity-utilization situations within each process, thus enabling promotion of company-wide improvements in engineering techniques.

Section 4

Humanized Production Systems

25

Cultivating the Spontaneous Kaizen Mind

§ 1 DEVELOPING THE SPONTANEOUS KAIZEN MINDSET: TOWARD EMBEDDING TPS

When Taiichi Ohno, the central figure in the construction of the Toyota Production System, was consulting on TPS and helping companies to introduce it, he never spoon-fed the people he was advising but made them think of their own improvement strategies and encouraged them to develop their own problem-solving abilities. In other words, he was always mindful of motivating the people on the shop floor, and fostering a spontaneous kaizen mindset in them.

However assiduously one teaches TPS techniques and systems to people, the systems will not take root nor have any possibility of development if the people are not motivated. Taiichi Ohno's method of guiding and developing people is the most important point about the way in which TPS is introduced and becomes established.

Whenever a company introduces TPS, it is usually with the help and guidance of a consultant, but it often fails to become established after its introduction, and everything slips back to square one. This is probably because the motivation of the people who are supposed to drive the ceaseless permeation, evolution, and development of TPS within the organization has not been developed. That is why developing highly motivated people is more important than anything else.

In this chapter, I introduce some examples (see Shimokawa and Fujimoto, 2001) from the time when Ohno was advising Daihatsu on the introduction of TPS, and from Ohno's own words and actions (Ohno, 1982). These examples will help shed some light on Ohno's consulting methods and explore the issue of developing motivation and the spontaneous kaizen mindset in order to embed TPS in the organizational culture.

§ 2 HOW TAIICHI OHNO CAME TO BE DAIHATSU'S CONSULTANT

In 1967, Daihatsu formed a business alliance with Toyota and joined the Toyota Group for the first time. Toyota entrusted the production of its small car the Publica to Daihatsu, and full-scale production commenced at Daihatsu's Kyoto Factory in 1973. The biggest issue Daihatsu faced at that time was how to produce the Publica at Toyota's levels of cost and quality.

It was in these circumstances that Taiichi Ohno, who was at that time Toyota's vice president with responsibility for manufacturing, began providing Daihatsu with advice and guidance on TPS. Up until then, TPS had only been introduced and disseminated within Toyota Group suppliers in the Nagoya area. Daihatsu was located a long way from Nagoya in Kansai and, as a Kansai company, undeniably had a corporate culture that was different from Toyota's. There was no way TPS could be transplanted into such a company simply by imposing it unilaterally.

The key person at Daihatsu who received advice and coaching directly from Taiichi Ohno was Michikazu Tanaka, who at that time was deputy head of the production department at Daihatsu's Kyoto Factory. (He later rose to become Daihatsu's president.) The way in which TPS was passed between Ohno and Tanaka, including Tanaka's reception toward it, not only gives us some ideas and knowledge for transplanting TPS, transferring it overseas, and making it take root in the corporate culture, but also underlines the importance of the human side of things in the transfer of TPS.

§ 3 CREATE A DIFFICULT SITUATION AND GIVE PEOPLE A PROBLEM TO SOLVE

In Ohno's method of consulting, the first thing he always did was to create a difficult situation for the people under him and give them a problem to solve. This was because he believed that people only really exercise their ingenuity when in a pinch.

His next principle was that he would not lead people by their noses to solutions but would always get them thinking and encourage them to develop their own problem-solving abilities. In Tanaka's words, this approach consisted of "teaching only 20 percent, while making people work out the remaining 80 percent for themselves."

Let's look at some case studies to see how this method worked.

Case 1: Mixed Assembly of the Starlet (the Successor to the Publica) and Daihatsu's Own Popular Car

Nowadays, it is standard practice to pass four or five different automobile models down the same production line, but in those days, the conventional wisdom was that it was impossible to make more than one model on the same line, and that each model had to have its own dedicated line. At Daihatsu in particular, where space was at a premium, the production engineers said that mixing production of two cars on the same line was totally out of the question, and that if they were forced to do so, they would need to construct a 10,000-square-meter building for the parts. Taiichi Ohno turned this down flat, saying that the Starlet was a cheap car, and that constructing a building of this size would raise fixed costs to the point where it would be impossible to achieve the vehicles' target cost determined through the target costing.

Tanaka's response to the problem thrust upon him by Ohno was to say, "Let's give it a go. You never know whether you can do something until you've tried it. If it doesn't work out, that's the time to rethink." He said this both to his boss (Daihatsu's vice president) and to Taiichi Ohno.

The factory's department and section managers gave Tanaka quite an ear-bashing with all their reasons for why it couldn't be done, but he imposed his firm resolve on them, telling them that he had made up his mind to make the cars on a mixed-model line and that he didn't want to hear any more reasons why it was impossible, only what would make it possible. He told them he wanted to work with them to identify and do whatever was needed to make it happen.

Faced with the strong determination of their boss, the managers then did their best to come up with some practical proposals for solving the problems. As an example, the press was at that time producing twelve shifts' worth of parts per lot; they halved this to six shifts' worth, freeing up space for parts. All the different departments of the factory came up with a succession of such proposals.

Case 2: Development of the *Ready, Set, Go!* System in the Body Welding Process

Nowadays, all the body welding in an automobile factory is done automatically by robots, but at the time it was done manually by human welders. The *Ready, Set, Go!* system in the body welding process was developed independently by Daihatsu under Taiichi Ohno's guidance. Taiichi Ohno didn't do it for them; he only provided them with a hint.

A detailed explanation of the *Ready, Set, Go!* system was presented in the first edition of this book (Monden, 1983) and can be seen in Chapter 10 of this fourth edition. Since it applies to manual spot welding processes, the system is not used in modern body shops, but its description has been left in this edition because its principles are fundamental to TPS. I saw it myself when I visited Daihatsu's Ikeda Factory in 1979, and it gave me such a shock that my whole body shivered with fear at how demanding it was.

The first line that Ohno went to see when he visited the factory was the main body process on the body line (the body line consisted of the main body process, a body process for each of the two side bodies, and the underbody process). After he had observed the main process for a while, he asked, "Tanaka, is that operator ahead or behind with his work?" Tanaka could not answer, since he did not know the state of progress of the operator's work.

Thereupon Ohno swiftly drew a chalk line on a nearby blackboard and said, "When you ran in a race at your elementary school sports day, there was always a start line, wasn't there? Everyone starts at the same time from the same spot, so it's obvious who is leading, who is in second place, and who is lagging behind, isn't it? If they all started at different times, no one would know who was in first or second place. It's the same on this production line at the moment; we have absolutely no idea who's ahead and who's behind with their work. If you can't see the problem, there's no way you can improve anything. You have to get everyone working as if they were working on a conveyor line, even when they're not, and you need a pacemaker in order to do that." This was the only advice Taiichi Ohno gave.

This was what led Tanaka and a production department manager called Takemoto whom Ohno had brought with him from Toyota to devise something that could act as a pacemaker. To make it something that would be easy for everyone on the body line to recognize, they decided to sound a buzzer at the passage of each takt time interval. This could be described as something of an invention.

A week later, Ohno returned and said, "That won't do at all. With a noisy buzzer like that, it feels as if the workers are being driven like cattle. We mustn't do anything that seems like forcing the workers along. How about playing a pleasant tune instead of buzzing? And you could let the workers themselves decide what tune they would like. And it shouldn't be installed only at one location on the line. Spread it out to three locations." We should not overlook the fact that Ohno here gave a piece of advice that moved things further in the right direction.

At the next opportunity, Ohno hit them with a new problem, saying, "It's no good knowing how far in front or behind things are just at every cycle (one takt time interval). You have to arrange things so that you know how the work is progressing within each cycle."

Tanaka therefore came up with the idea of breaking each cycle down into five parts and playing music each time one of those parts had elapsed. In other words, a different melody was played at every fifth of a takt time interval. The workers could then hear when a fifth of the takt time had elapsed, when two-fifths had elapsed, when the complete cycle had elapsed, and so on.

In addition, the amber lamp of each andon was made to light up at the point in time when four-fifths of the takt time had passed, the green lamp for the process where the work had been completed, and the red lamp for the process where the work was behind. (This system, in which the takt time is divided into equal intervals and a different tune is played at the end of each interval to control the progress of the work, is still used for the internal setup procedure of the presses at Daihatsu.)

In this way, everything started again all at once on each main and side body process at the point in time when all the work had been finished, and this is what is meant by "On your mark—go!" Everything repeatedly started at the same time. This is the similar approach called *the takt system* in production management textbooks, for synchronizing everyone's work on conveyorless lines.

Case 3: "You Mustn't Think, 'What Am I Going to Teach Them?'"

One day, Ohno brought a man called Imai with him to Daihatsu, saying, "I've brought you an ideas man." After observing the shop floor at Daihatsu closely for a week, Imai said to Ohno, "I couldn't think of anything that I needed to do at Daihatsu; nothing occurred to me." Ohno told him, "You mustn't think, 'What am I going to teach them?' It's much more important to draw out suggestions from the workers themselves and then help them. That's your job." He also gave Imai a hint, suggesting that he try to make progress on some small automation improvements.

Imai then started doing what Ohno had suggested, and Tanaka came across him once late at night on the shop floor, tackling some improvements with the operators. What Imai said to Tanaka at that time left a strong impression on him.

Imai said, "If you want to make a good improvement, you need the workers' cooperation. If you try to do it by yourself, you can only achieve half of what you want to achieve, but with positive advice from the operators, you can do it all. There's no way we can improve things without getting the workers to help us." This attitude must have made itself felt to the workers; after that, they asked Imai to improve all sorts of things. Trust had arisen between him and the employees.

Until then, Tanaka had thought that his job was to get his subordinates to do things by telling them what to do. He had not thought it important to elicit suggestions from them. Imai taught him that his job was to draw out the workers' ideas and creativity.

§ 4 CONCLUSIONS

In this chapter, I have explored how to develop the spontaneous kaizen mind-set (i.e., motivation) with a view to establishing TPS as part of the culture, while looking at some specific examples of Taiichi Ohno's teaching methods.

What we can conclude from this is that Ohno considered people's motivation to be more important than anything else for improving the shop floor. We can say that Ohno used the following three strategies to foster this kind of motivation.

1. Get People to Exercise Their Ingenuity by Creating a Difficult Situation and Giving Them a Problem to Solve

Rather than teaching them specific TPS techniques and systems, Ohno would deliberately create an extremely demanding situation on the shop floor and give the people there a real problem so they were forced to exercise their creativity and ingenuity whether they wanted to or not. This is clear from three cases above.

In Case 1, he directed the factory to make two different models on the same line, even though the conventional wisdom at the time was that every model had to have its own dedicated line. What's more, he did this at a factory where space was in short supply and the production engineering department was resisting strongly, saying that it was totally out of the question.

In Case 2, the only thing he told them to do was to devise a pacemaker so that, in the conveyorless body welding process, all the welders would weld in synchronization in accordance with the takt time, just as if they were working on a conveyor.

What these cases have in common is that Ohno posed a challenge to the shop-floor people by giving them a tough problem to solve.

However, he didn't merely go around giving his subordinates a headache. He also said the following (Ohno, 1982, 140–141):

> When leading a large number of people, basically, you need not just to give orders and advice but also to engage in a battle of wits with them. If you give an order or instruction, you have to work out how you yourself would carry it out, as if you yourself had received the same order or instruction. And if their idea is better than yours, you have to admit defeat with good grace. It's all about working with your people—going through the pain with them, racking your brains with them, giving them as many suggestions as you can. You have to work out what it is that will make them stick with you. I talked about "a battle of wits"—you need to be aware that people only come up with ideas when they're in a fix. You need to think about how to put your people on the spot. What would give them a real headache? When it's a matter of life and death, people always come up with good ideas. If you tell someone to do something but have no idea how to do it yourself, even if you want to put them on the spot, you'll have nothing to say if they come back to you and tell you they can't do it. They won't be bothered by that at all. To put such pressure on them that they feel they have to watch themselves carefully in case they inadvertently say that it can't be done, you have to rack your brains and come up with some good ideas yourself, at least as good as any they can come up with, at the same time as you're telling them what you want.

It is certainly true, as Ohno says here, that whenever he gave the people under him a challenging task, he himself did his utmost to come up with a solution. I remember that when he and I were both lecturing at a TPS workshop and were sitting in the anteroom together, he kept furrowing his brow and saying, "I'm consulting at a certain company at the moment, and I'm wondering how they can apply the kanban system to a particular component." Most consultants don't go to so much trouble for their clients. This also relates to point (3) below, regarding lending a helping hand.

Daihatsu's Michikazu Tanaka arrived at the following interpretation of the kanban system:

> As far as the kanban system was concerned, I used to think that it was simply something for reducing WIP, increasing productivity, revealing problems, and so forth. This is certainly true, but Mr. Ohno's aim was to reduce WIP and create a very tough situation in order to motivate people. He used the kanban system as a tool for this purpose. His ultimate goal was to motivate people. (Shimokawa et al., 2001, p. 36)

2. Never Lead People by Their Noses to the Solution of the Problem but Always Make Them Come Up with Their Own Improvement Strategies, and Encourage Them to Develop Their Own Problem-Solving Abilities

In Case 3 above, Ohno told the shop-floor kaizen adviser, "You mustn't think, 'What am I going to teach them?' It's much more important to draw out suggestions from the workers and then help them." This was his philosophy on promoting kaizen.

This meant "telling them only 20 percent of the solution, while making them work out the remaining 80 percent for themselves." In other words, he thought that when introducing or advising on TPS, it was essential not to spoon-feed people but to make them come up with their own improvement ideas and develop their own problem-solving abilities. Specifically, it is clear that even in Cases 1–3 above, Ohno only provided the problem and a few hints as to how it might be solved, and had the responsible people in the area think up their own solution. However, with the buzzer that acted as the pacemaker in Case 1, he proposed the further improvement of replacing the buzzing sound with an agreeable melody.

3. Even If Your Subordinates Fail, Do Not Communicate a Feeling of Frustration to Them; Lend Them a Helping Hand—Leaders Should Become Charismatic People on Whom Others Can Rely

Ohno also said the following: "To get people to do what you are asking them to, you have to become someone with charisma. You have to try to become the sort of person to whom others are so attracted that they would walk through fire for you" (Ohno, 1982, pp.141–142).

What Ohno is asking for here (to become someone with charisma) is not easy for ordinary people to do. On this point, Tanaka reveals that he was told by Ohno that he (Tanaka) was very harsh on his subordinates and was warned by Ohno not to give motivated people a feeling of failure. Ohno didn't simply set people difficult challenges; he also said that even if they didn't think they could accomplish something, motivated people were at least prepared to try, but that sometimes they didn't succeed. When that happened, it was wrong to make them feel they had failed.

Tanaka thought long and hard about the fact that he had until then only had harsh words for his subordinates. According to him, when he stopped scolding so much and started lending a hand, people started to see him as someone who appreciated their efforts, even if things didn't always go as planned, so they would try anything for him. He ended up saying that "People who don't lend a hand are not trusted" (Shimokawa et al., 2001, p. 50).

In other words, when we give someone a difficult problem to solve and they try their best to solve it, we should recognize the journey they have made. In today's real-world economic society, people are evaluated on their results, and effort without results is often considered meaningless, but if we avoid making someone who has tried their best feel as if they have failed, they are much more likely to try their hardest on the next challenge. A leader with charisma is someone who is not merely tough all the time but who responds to people more sympathetically; people will listen closely to such a leader and do their best to improve.

We can say that Taiichi Ohno developed TPS and set about introducing it into organizations while trying to develop people based on the three strategies described above. For improving the workplace, his approach to people development boiled down to getting them motivated. The people who were developed in this way in turn developed the people under them using the same approaches, which is probably why TPS in the Toyota Group has continued to evolve without any apparent limits. This could be considered similar to the master-pupil relationship chain in the academic world, in which learning is passed down through time.

Even in academia, those considered to be first-class teachers are probably those who give their students a broad-ranging and difficult but interesting research topic and then do not spoon-feed them in conducting their research or writing their theses. First-rate teachers do not lead their students by the nose, and it would be impossible to develop first-rate researchers with that kind of teaching. The students initially have to take their broad-ranging research topic given by the teacher and find through their own efforts a more specific research topic within it that they can work up into a thesis. Then they have to find their own way to elucidate the topic of the research. However, there are quite a few time constraints on young researchers when they are preparing their theses to obtain their doctorates, so if they have done all they can and still do not know what route their research should take, how to solve the problems, or what methods to use, their teacher should offer them some hints. Nevertheless, the students themselves should use their own creativity and conduct the research themselves, based on those hints. This kind of process will develop researchers with true research abilities.

Finally, when students have tried as hard as they can and have still not gotten any results, the teacher should not rebuke them and make them feel they have failed, but should praise them for their efforts and extend a helping hand to them so that they will come up with fresh ideas and improvements. When students who have received this kind of mentoring become teachers, they will probably in turn mentor their students in the same way and develop their own "schools" of learning.

26

Improvement Activities Help Reduce the Workforce and Increase Worker Morale

§ 1 RESOLVING THE CONFLICT BETWEEN PRODUCTIVITY AND HUMAN FACTORS

The Toyota Production System attempts to increase productivity and reduce manufacturing costs. Unlike other such systems, however, it reaches its goal without a loss in the human dignity of the worker. As has often been pointed out in connection with the conveyor belt system developed by Henry Ford, attempts to increase productivity are usually accompanied by an increased demand on the individual worker. To increase productivity, one must either maintain the same level of production while reducing the size of the workforce or produce more and more with the existing number of workers. Traditionally, either alternative has involved an unacceptable sacrifice in human terms—a dehumanization of the worker. At Toyota, however, the conflict between productivity and human concerns has been resolved by initiating positive improvements at every workplace through small groups called *quality control circles* (QC circles).

The improvements are varied: refinement of manual operations to eliminate wasted motion, introduction of new or improved machinery to avoid the uneconomical use of manpower, and improved economy in the use of materials and supplies. All three types of improvements are evolved by means of small group meetings in which a suggestion system similar to that employed in other countries plays a prominent part.

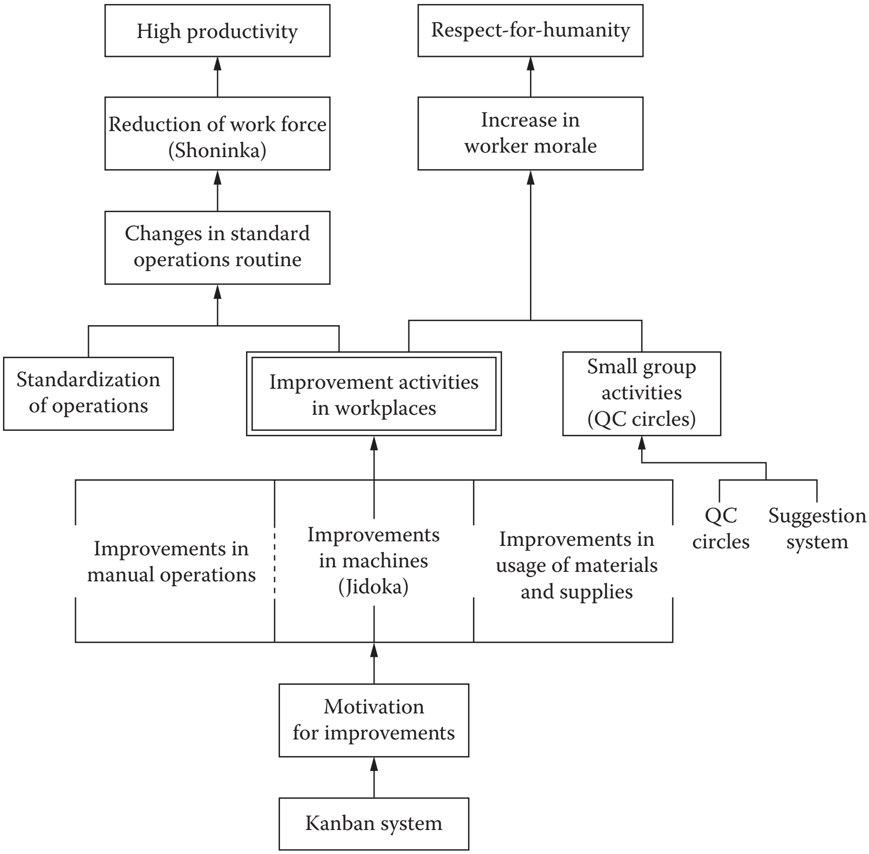


FIGURE 26.1
Framework of improvement activities.

In addition, the kanban system also functions to promote improvements in productivity. In all likelihood, it is the only production control system that also provides a motivation for improved productivity. Figure 26.1 shows the relationships between the kanban system, various improvements in the workplace, quality control circles, and increased productivity and morale.

§ 2 IMPROVEMENTS IN MANUAL OPERATIONS

In any factory, all manual operations fall into one of the following three categories:

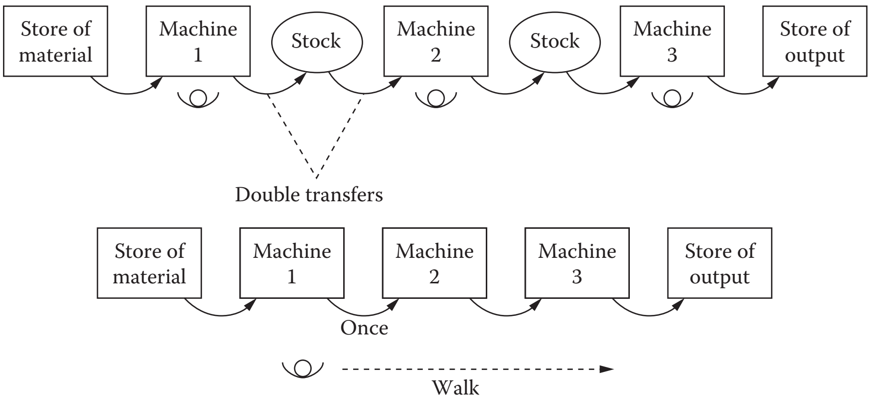


FIGURE 26.2
Elimination of double transfer.

- *Pure waste*—Unnecessary actions that should be eliminated immediately (i.e., waiting time, stacking of intermediate products, and *double transfers*; Figure 26.2).
- *Operations without value added*—Operations that are essentially wasteful but may be necessary under the current operating procedures. They include walking long distances to pick up parts, unpacking vendor parcels, shifting a tool from one hand to another, and so on. To eliminate such operations, it would be necessary to make changes in the layout of the line or arrange for vendor items to be delivered unpackaged—none may be practical at the present time.
- *Net operations to increase value added*—Conversion or processing operations that increase the value of raw materials or semi-finished products by adding manual labor (e.g., subassembly of parts, forging raw material, tempering gears, painting body work).

Also, remedial operations—operations to repair or remove defective products, tools, or equipment—are found in all factories.

Net operations to increase value added typically constitute only a small portion of total operations, but most of these serve only to increase costs (Figure 26.3). By raising the percentage of net operations to increase value added, labor required per unit can be reduced, thus reducing the number of workers at each workplace. The first step is to eliminate pure waste. Next, reduce operations without value added as far as possible without incurring unreasonable costs. Finally, examine even net operations to increase value added to see if they can be further increased as a proportion

Manual operations		
Pure waste	Operations	
	Operations without value added	Net operations with value added

FIGURE 26.3
Categories of operations.

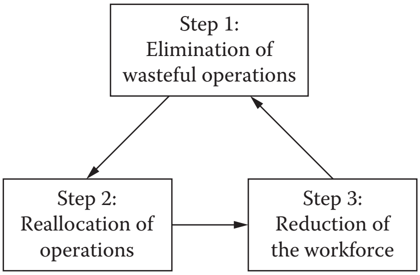


FIGURE 26.4
Cycle for reducing the number of workers.

of total operations by introducing some type of automatic machinery to take the place of operations currently being carried out by hand.

§ 3 REDUCTION OF THE WORKFORCE

When making improvements to reduce the number of workers on its combined U-form lines, Toyota eliminates wasteful operations, reallocates operations, and reduces the workforce. These three steps are really parts of a cyclical process: elimination of purely wasteful operations (waiting time) immediately leads to reallocation of operations among workers at the workplace and a partial reduction in the workforce. The three steps may be repeated several times before all possible improvements to the line have been made (Figure 26.4).

The first step toward reducing the number of workers is to determine the waiting time for each worker and revise the standard operations routine to eliminate it. Waiting time is often hidden behind overproduction and so never comes to light. In such cases, large amounts of inventory

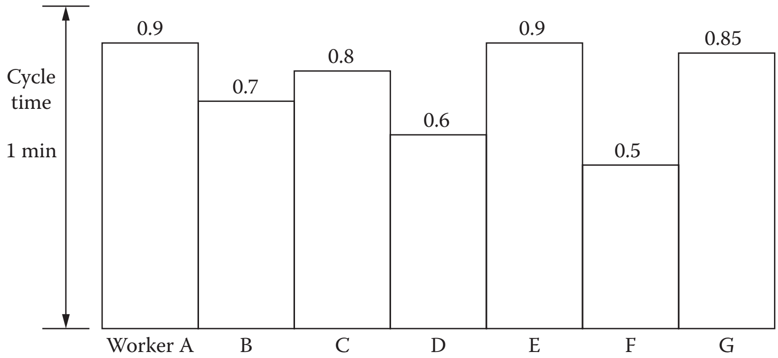


FIGURE 26.5
Each worker has waiting time.

are behind or between processes. As a result, actions such as moving and stacking inventory, which occupy much of a worker's waiting time, are often regarded as part of his job. At Toyota, however, such actions are classified as a waste of overproduction, and the kanban system, which serves to reduce inventory levels, makes the waste of overproduction obvious. Kanban plays an important a role in eliminating wasteful operations by standardizing operations.

To illustrate how eliminating waiting time and reallocating operations leads to a reduction in the workforce, consider the following example. Seven workers, A through G, are all working at the same workplace. The standard operating time for the operations assigned to each worker must be measured. By subtracting the standard operating time for each worker from the cycle time, waiting time during each cycle for each worker can be determined. If, for example, the cycle time is one minute per unit of production and the total standard operations assigned to worker A take 0.9 minutes, he will have 0.1 minutes of waiting time. In most cases, each of the other workers will also have waiting times of varying length (Figure 26.5).

To eliminate waiting time, some of worker B's operations must be transferred to worker A, some of worker C's operations to worker B, and so forth until enough operations have been reallocated to eliminate the waiting time for workers A through E. At this point, worker G's job will have been eliminated altogether (Figure 26.6).

When reallocating operations among workers—either to bring about improvements in manual operations or to compensate for changes in production levels—the following three rules should be observed:

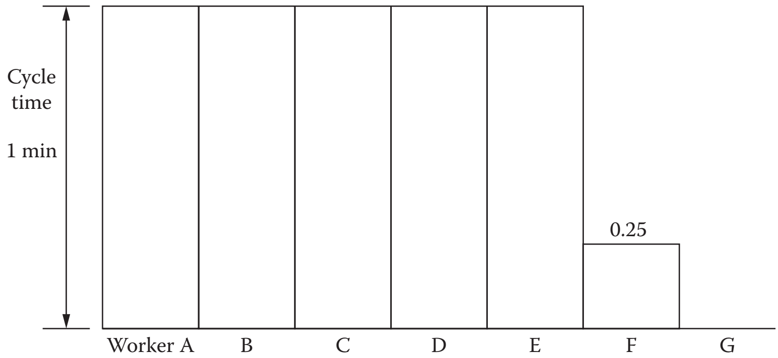


FIGURE 26.6
Reallocation of operations among workers.

1. When the waiting time for each worker is being measured, he should stand without doing anything at all after finishing the operations assigned to him. If worker B, for example, finishes his job in 0.7 minutes he should simply stand idle at his workstation for the remaining 0.3 minutes. In this way, everyone will be able to see that he has free time, and there will be less resistance if he is assigned one or two more jobs.
2. When reducing the number of workers at a workplace, the best worker(s) should always be removed first. If a dull or unskilled worker is moved, he may resist, his morale may suffer, and he may never develop into a skilled worker. An outstanding worker, by contrast, is usually more willing to be moved since he has more self-confidence and may welcome the opportunity to learn other jobs in the factory.
3. After operations have been reallocated to workers A through E, the 0.75 minutes of waiting time for worker F should not be disposed of by distributing it equally among the six workers remaining on the line. If it were, it would simply be hidden again, since each worker would slow down his work pace to accommodate his share of the waiting time. Also, there would be resistance when it came time to revise the standard operations routine again (Figure 26.7). Instead, a return to step 1 is necessary to see if further improvements can be made in the line to eliminate the fractional operations left for worker F.

All three types of manual operations must be examined, including net operations to increase value added that might be omitted through introduction of an automatic machine. At this state, however, it is important to

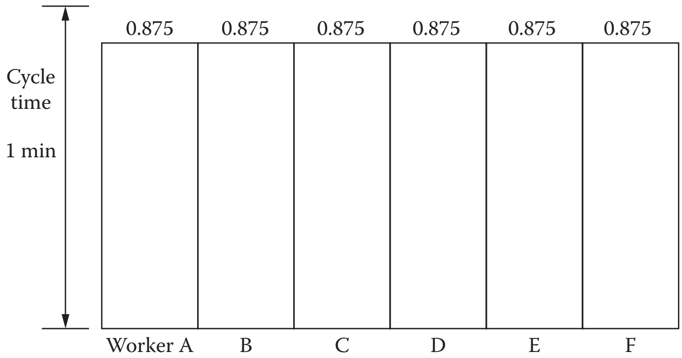


FIGURE 26.7
Wrong allocation of operations.

choose the least expensive plan, since only 0.25 minutes of manual operating time needs omitting. Less expensive improvements include the following:

- Move parts supplies closer to the worker or introduce chutes to shorten walking distances.
- Use smaller pallets that can be placed beside workers who need only a small number of parts at a time.
- Redesign a tool to eliminate the wasted motion in changing it from one hand to the other.
- Make it easier to pick up tools by hanging them in racks with their handles uppermost.
- Introduce some simple tools to streamline operations.
- When a worker operates more than one machine, locate the on/off switch between the two machines so it can be pushed while the operator is walking from one machine to the other.

By means of one or more of the aforementioned devices, it should be possible to eliminate the 0.25 minutes of operating time remaining for worker F and so remove him from the line. Thus, in our example, it would be possible to eliminate two out of seven workers. Look at the line again for previously overlooked wasteful operations and attempt to remove another worker by eliminating other operations without value added. Improvements to the line at this point are difficult; some improvements that are intrinsically worthwhile may be held in reserve until a sales or model change makes it possible to alter the cycle time or the design of the workplace.

§ 4 IMPROVEMENTS IN MACHINERY

In any manufacturing process, two kinds of improvements exist: improvements in manual operations and improvements in machinery. The first involves definition of standard operations, reallocation of operations among workers, relocation of stored parts and semi-finished products, etc. The second type of improvement involves introduction of new equipment such as robots and automatic machines. At Toyota, improvements in manual operations are always undertaken before making improvements in machinery. The reasons follow:

- From a cost-benefit standpoint, machine improvement may not pay. Remember that the purpose of any improvement is to reduce the number of workers. If the same purpose can be achieved through improvements in manual operations, it will not pay to install a new schedule.
- Changes in manual operations can be reversed if necessary, while those in machinery cannot. Thus, if a machine improvement ends in failure, the machine is a total loss. The costs of improvements in manual operations, on the other hand, are at least partially recoverable.
- Improvements to machinery often fail if they are made before improvements in manual operations. Since an automatic machine is inflexible in its operation, it can be successfully integrated into a line only if all manual operations have already been standardized. Otherwise, improper processing of the work piece and operation of the machine may result in any unacceptable number of defective parts and the machine itself may break down frequently. If an automatic punch press, for example, was installed where the wrong types of material might be placed in the machine, the die could be permanently damaged and the machine along with it. As a result, it would be necessary to assign a watchman to the machine and its value as a labor-saving improvement would be reduced considerably.

Policies in Promoting Jidoka

Autonomation or *jidoka* is essentially improving machinery to reduce the number of workers. There are two problems, however, that should be considered when promoting jidoka:

1. Even if the introduction of an automatic machine reduces manpower requirements by 0.9 persons, it cannot actually reduce the number of workers on the line unless the remaining 0.1 person (which is often the watchman for the machine) can also be eliminated. As a result, introduction of the machine serves only to increase manufacturing costs and thus the cost of the product. To put the matter a different way, a reduction in the man-hours required to produce a unit (*Shoryokuka*) is not the same thing as a reduction in the workforce. For this reason, a true reduction in the workforce is called *Shoninka* at Toyota to distinguish it from Shoryokuka. Only Shoninka can reduce the cost of an automobile.
2. Jidoka often has the undesirable effect of fixing the number of workers who must be employed at a given workplace; that is, while jidoka replaces manual operations, it may also require a certain number of workers to help the machine by performing operations that cannot be automated. As a result, the same number of workers must always be present to operate the machine regardless of production quantity. At Toyota, this phenomenon is called a *quorum system* ("Te-i-in-se-i"), which is an undesirable phenomenon in any business.

In both respects, then, introduction of jidoka may actually limit the ability to reduce the number of workers—a matter of some concern, since it is always essential to be able to reduce the workforce, especially when demand decreases. How can the two problems be solved? How can Shojinka (flexibility in the number of workers) be maintained when introducing jidoka? Toyota has two policies:

1. Automatic machines should be introduced only when a strong need exists, not simply because the manual operation in question can be replaced by a machine.
2. The workstations at a machine should always be located as close together as possible, especially when the machine occupies a large area, as is the case with a transfer machine. Too often, the workstations are widely separated, and each worker's operation time at the machine per cycle is fractional. As a result, it is impossible to combine fractional manpower operations into integer operations when the workforce must be reduced.

§ 5 JOB IMPROVEMENTS AND RESPECT FOR HUMANITY

When making job improvements, respect for humanity can be maintained by observing the following rules.

Give Workers Valuable Jobs

Reductions in the workforce are sometimes regarded as a way of forcing hard work on workers without consideration for their humanity. This criticism, however, is based on a misunderstanding of the nature of job improvements or in cases where the wrong procedure has been adopted. When operations at a workshop are improved, each worker must understand that the elimination of wasteful actions will never lead to harder work. Instead, the goal of the improvement program is to increase the number of net operations with added value that can be performed with the same amount of labor. For example, suppose a worker on a trimming line must walk five or six steps to pick up a part and climb in and out of the car several times during each cycle. The function of job improvement is to eliminate such wasteful actions and use the time instead to perform net operations with added value, thus reducing the total standard operations time and the number of workers. Unless this point is fully understood, the Toyota Production System is hard to apply, especially in an environment where the labor union is strong.

At Toyota, then, respect for humanity is a matter of allying human energy with meaningful, effective operations by abolishing wasteful operations. If a worker feels that his job is important and his work significant, his morale will be high; if he sees that his time is wasted on insignificant jobs, his morale will suffer as well as his work.

Keep the Lines of Communication within the Organization Open

The approach used to promote job improvements is very important. A mere injunction to "Reduce the number of workers!" or "Improve the process!" is not enough to solve the problem. Every workshop has its problems and workers are usually interested in solving them. A worker may complain, for example, that his operation is hard to do because of crowded conditions at his workstation or that the machine is hard to adjust and leaks oil. When the worker notifies his supervisor about such problems, however, the supervisor may not pay attention or repair personnel may not attend to the problem on a timely basis. When this happens, an exceptional worker may try to solve the problem himself—and fail, especially if the solution requires that a machine be redesigned or modified. In most cases, however, the worker will simply lodge a complaint with the labor union and resistance to the manager will come out. (A representative case is described in Runcie [1980].) If, on the other hand, the supervisor responds quickly and effectively, the worker will trust his supervisor and feel that he has an active role in efforts to improve the shop.

A relationship of trust and credibility is most important in promoting improvements. To establish such a relationship, however, the formal lines of communication from the lower-level workers through to the foreman and general foreman up to the superintendent must be well drawn and open since any problem must be solved through these channels. If the supervisors and IE staff respect proposals from the workshop and promote improvements together with workers, each individual in the factory will have high morale and an awareness of his role in improvement activities. No one will feel alienated, and every worker will feel that his work is an important part of his life.

§ 6 THE SUGGESTION SYSTEM

Although the stated purpose of any suggestion system is to draw upon the ideas of all employees to improve company operations, its real purpose is often quite different. In such cases, the suggestion system is intended simply to give an employee the sense that he is recognized by his company or his superior, or to build loyalty and company pride by allowing him to draw up plans as if he were a member of management. In other words, the real purpose of a suggestion system in most companies is labor or personnel management.

At Toyota, however, both the purpose and spirit of its suggestion system are expressed in the slogan: "Good products, good ideas"—that is, its goal is to draw upon the ideas of all employees in order to improve product quality and reduce costs so the company can continue to grow in the world automobile market. This is not to say that Toyota is oblivious to the effect of a suggestion system on labor relations, but it is some index of the seriousness with which Toyota takes its employees' suggestions that most of the improvement activities described in this chapter were initiated through a company-wide suggestion system.

Individual improvement schemes are devised and introduced by an individual worker or by *QC circles* composed of workers at each workplace led by the supervisor. When one of the members of the group calls a problem to the attention of the supervisor, the supervisor takes the following steps:

1. *Define the problem*. In considering the problem, the supervisor should attempt to determine the exact nature of the difficulty and its effect(s) on other operations and workers.
2. *Examine the problem*. Present conditions must be examined in detail to determine the causes of the problem. In the process, other related problems may also come to light.
3. *Generate ideas*. The supervisor should encourage the worker to generate ideas for solving the problem. For example, suppose a worker has pointed out that it takes him a great deal of time to count the number of units on a pallet and that the pallet often contains several different kinds of parts. The worker might then suggest that frames be installed in the pallet to make it easier for him to count the number of parts it contains and to separate one kind of part from another (Figure 26.8). Or an equally good solution may be evolved by the

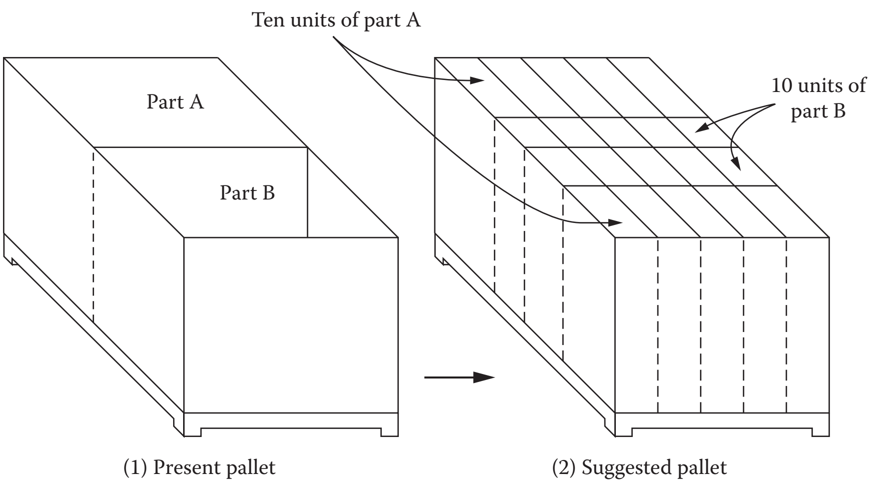


FIGURE 26.8
Example of suggestion scheme.

group as a whole. In either case, the supervisor should always show respect for his subordinates' ideas.

4. *Summarize ideas*. The supervisor should summarize the various proposed solutions to the problem and allow his subordinates to select the best scheme.
5. *Submit the proposal*. One member of the group should write the selected scheme on a suggestion sheet and put it in the suggestion box. Although many suggestions for improvements are generated by means of QC circles, individual ideas for improvements can be submitted at any time without consulting with the supervisor or another group member. Nor is it necessary for a problem to arise in order for the group to operate as a source for suggested improvements.

Toyota uses the following checklist of topics for QC circle meetings:

Improvements in manual operations:

1. Is it appropriate to store materials, tools, and products in the present way?
2. Is there any easier way to manage machine handling or machine processing?
3. Can you make your job easier and more efficient by changing the layout of machines and conveyance facilities?

Savings in materials and supplies:

1. Are oil, grease, and other supplies being used efficiently?
2. Is there anything that can be done to reduce leakage of steam, air, oil, etc.?
3. Can you reduce the consumption of materials and supplies by improving materials, machining methods, and jigs?

Improving efficiency in the engineering department and in offices:

1. Are there jobs in your office that overlap?
2. Are there any jobs that could be eliminated?
3. Could you improve the present voucher system?
4. Could your job be standardized?

Improving the work environment to increase safety and prevent dangerous accidents:

1. Are the lighting, ventilation, and temperature conditions good?
2. Are dust, gas, and bad odors fully removed from the work area?
3. Is your safety equipment appropriate: Does it function well?

Improving efficiency and uniformity of the automobile itself:

1. Can the quality of the automobile be improved by changing its design and manufacture?
2. Is there any way to increase the uniformity of the product?

Although the procedure for proposing improvements is much the same at Toyota as it is in America and European countries, the system for evaluating the proposals is quite different and far more effective because it is carried out in a rapid and orderly fashion. The assessment of proposals follows the path through the organization shown in Figure 26.9 and consists of the following steps:

1. All suggestions are gathered at the plant office on the first day of each month and recorded in the suggestion ledger.
2. Each Plant Sectional Committee examines the suggestions by the twentieth of the month and determines which plans deserve rewards of 5,000 yen or less.
3. The Plant Committee or Department Committee then examines plans which deserve a reward of at least 6,000 yen.
4. Plans which deserve a reward of at least 20,000 yen are examined professionally by a corporate-wide Suggestion Committee.
5. An official announcement of the results of the examination is published in the evaluation result table and in the Toyota newspaper.

All plans that have been adopted are implemented immediately. In some cases, a plan will be designated "pending" and examined again the following month. Other plans, designated "reference," may be improved by committee members or managers and used later. If any type of plan contains patentable material, the committee notifies the person responsible for the suggestion and then submits the plan to an Invention Committee for appropriate action. All patents are applied for under the company name. The rewards are usually kept by each group and used for recreational activities such as trips or fishing parties.

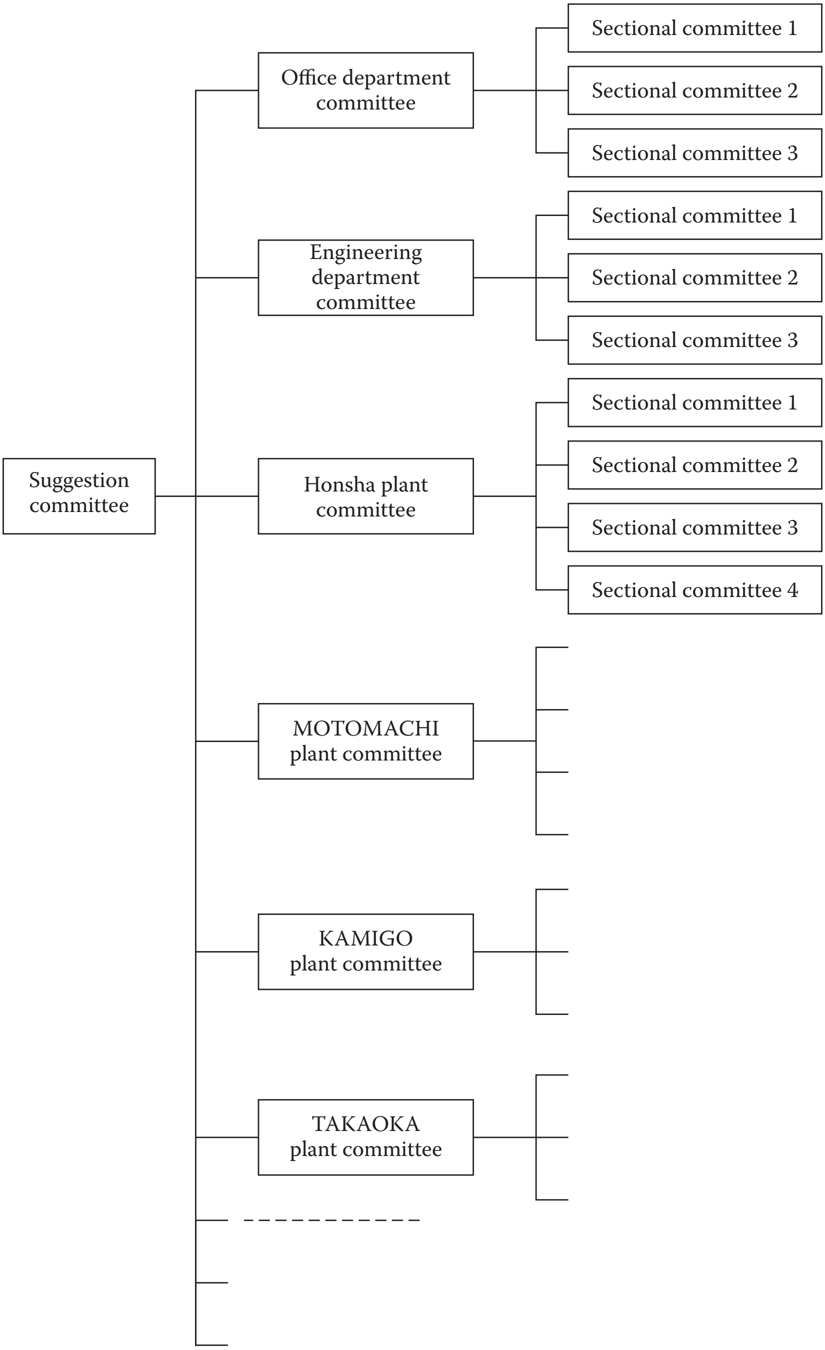


FIGURE 26.9
Organization of suggestion system committees.

In addition to monetary rewards, other kinds of commendations are awarded:

- For outstanding proposals, the company gives a testimonial to the person or persons responsible at a ceremony held each month.
- On a yearly basis, commendations are awarded to the person with the largest total amount of rewards, the largest average reward per suggestion, and so on.
- Any employee who has been given yearly commendations for three years in a row is given a special testimonial and a commemorative gift.
- A yearly testimonial and trophy can also be awarded to outstanding groups.

The suggestion system at Toyota was introduced in June 1951. Figure 26.10 shows the number of proposals, historically. It does not show, however, that there were about 53,500 workers at Toyota in 1984, including office workers. Thus, after 1984, each worker suggested an average of more than 40 improvement plans each year, most of which (95%) have been adopted. After 1987, however, Toyota began to put more emphasis on the quality of proposals instead of on the number of proposals, resulting in the average number of proposals per person decreasing to 30.

In summary, the suggestion system has the following advantages:

- The system operates through individual workers or QC circles where the supervisor of each group can give his subordinates' problems and proposals sincere and immediate attention.
- Proposals are examined every month on an orderly schedule and the results are announced immediately.
- The evaluation process establishes a close relationship between workers and the professional staff. For example, if a suggested improvement involves a change in design, a professional engineer will examine it immediately.

§ 7 KANBAN AND IMPROVEMENT ACTIVITIES

Everyone wants to take it easy, and, in this respect, the Japanese are no different from people in other countries. When inventory levels are high, things seem to go better for everyone: if a machine breaks down or the

Year	Number of Suggestions	Number of Suggestions/ Person	Participation Rate (%)	Adoption Rate (%)
1976	463,442	10.6	83	83
1977	454,552	10.6	86	86
1978	527,718	12.2	89	88
1979	575,861	13.3	91	92
1980	859,039	19.2	92	93
1981	1,412,565	31.2	93	93
1982	1,905,642	38.8	94	95
1983	1,655,868	31.5	94	95
1984	2,149,744	40.2	95	96
1985	2,453,105	45.6	95	96
1986	2,648,710	47.7	95	96
1987	1,831,560	--	--	96
1988	1,903,858	--	--	96

FIGURE 26.10
Number of proposals in recent years.

number of defective parts increases suddenly, subsequent operations need not stop so long as there is sufficient stock in inventory; and when the required number of units are not produced during regular working hours, it is usually unnecessary to schedule overtime in order to meet production goals. As long as problems like these are hidden behind high inventory levels, however, they cannot be identified and eliminated. As a result, they will continue to be responsible for various kinds of waste: wasted time, wasted labor, wasted material, and so on.

By contrast, when inventory is minimized by just-in-time withdrawals under the kanban system, such problems are impossible to ignore. If, for example, a machine breaks down or begins producing defective parts, the whole line will stop and the supervisor must be called in. In many cases, it will be necessary to schedule overtime hours in order to make up for lost production time. As a result, activities to correct the problems will take place in the appropriate QC group, plans for improvements will be

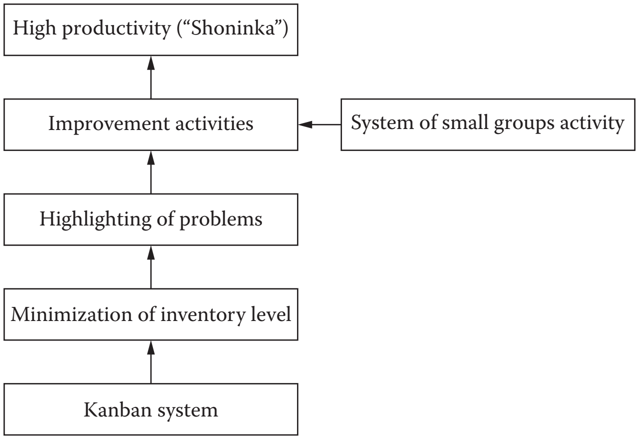


FIGURE 26.11
Relationship between kanban system and improvement activities.

devised, and productivity will rise. The function of the kanban system is not merely to control production levels. Its more important role lies in its ability to stimulate improvements in operations that eliminate waste and improve productivity. Figure 26.11 shows the relationship between the kanban system and improvement activities.

Toyota has expanded its improvement activities to all departments, including indirect divisions. In 1980, Toyota had 48,000 employees, 20,000 of whom were manual laborers in factories. The performance of the remaining 28,000 people, in indirect departments, however, had an important effect on what happened in the workplace. The jobs at departments such as quality control, cost control, product design, and production control, for example, all affected the performance of direct departments. Thus, in correcting individual problems at the workplace, Toyota has more than once found it necessary to make improvements in indirect departments as well. As a result, improvement activities in manufacturing operations have brought with them company-wide improvements.

Reductions in the workforce brought about by workshop improvements may seem to be antagonistic to the worker's dignity since they take up the slack created by waiting time and wasted action. However, allowing the worker to take it easy or giving him high wages does not necessarily provide him an opportunity to realize his worth. On the contrary, that end can be better served by providing the worker with a sense that his work is worthwhile and allowing him to work with his superior and coworkers to solve the problems they encounter.

§ 8 QC CIRCLES

A *quality control circle*, or *QC circle*, is a small group of workers that study quality control concepts and techniques spontaneously and continuously in order to provide solutions to problems in their workplace. At Toyota, the ultimate purpose of QC circle activities is to promote a worker's sense of responsibility, provide a vehicle to achieve working goals, enable each worker to be accepted and recognized, and allow improvement and growth in a worker's technical abilities. The purpose of the QC circle is somewhat different from that of the suggestion system outlined previously. The evaluation for QC circle activities is hardly made in terms of the monetary amount of improved effects, but rather by how positive the circle is acting, how well the subject (topic) is pursued, and to what degree the members are participating. (QC circle activities at Toyota was borrowed from Ozaki and Morita, 1981, but the systems below described are not basically changed as of today.)

Structure of the QC Circle

The QC circles at Toyota have a direct relationship with the formal organization of the workplace; therefore, all employees must participate in some QC circles. The QC circles are made up of a team leader ("Hancho") and his subordinate workmen (Figure 26.12). The QC circle may take the form of a *united circle* where members of other circles participate or a *mini-circle* that consists of a subgroup of members from the entire circle, depending on the topic to be solved. The supervisor or section head ("Kocho") and the foreman ("Kumicho") act as advisor and subadvisor, respectively.

Each plant or division has its own QC promoting committee (Figure 26.13). At Toyota, QC circle activities are supported by the highest responsible person at each plant. The personnel division and the education division recently have begun promoting QC circle activities. As of 1981, about 4,600 groups of QC circles were active at Toyota; each group averaged 6.4 members.

QC Topics and Achievements

The subjects QC circles select as problems to be solved are not confined to product quality; cost reduction, maintenance, safety, industrial pollution, and alternative resources are considered as well. In 1981, the subject breakdown was as follows: product quality, 35 percent; maintenance, 15 percent; cost reduction, 30 percent; and safety, 20 percent. The number of achieved

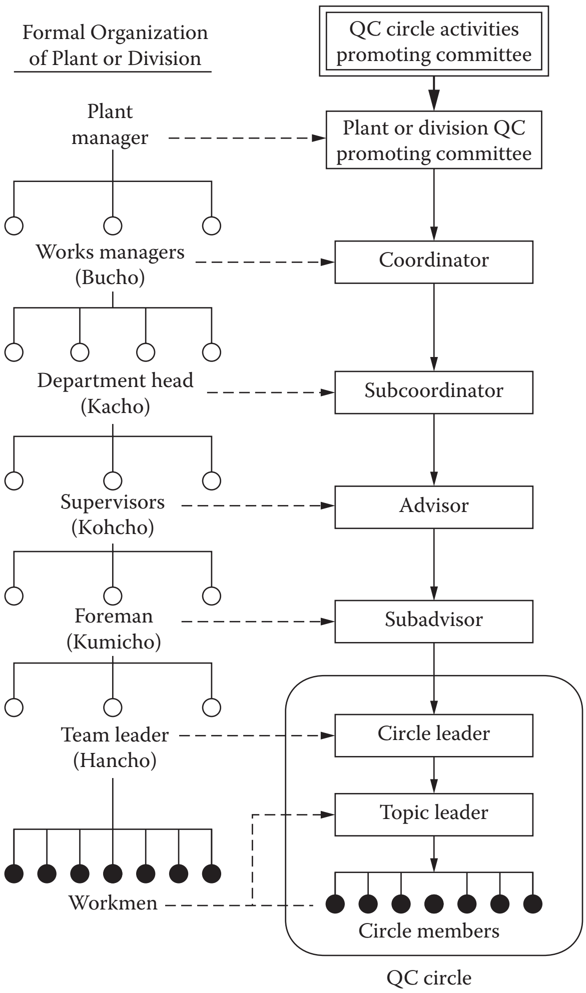


FIGURE 26.12
Structure of the QC circle and its relationship to the formal organization.

topics in each circle averaged 3.4 per year. Since the economic effect itself is not the only purpose, 3–4 subjects are settled as a goal to be achieved each year.

The number of circle meetings actually held was 6.7 times per year for each topic, and each topic required an average of 6.4 hours. Therefore, each meeting was approximately one hour in length. It is considered best at Toyota to have the circle meeting two or three times each month and approximately thirty minutes to one hour in duration. Figure 26.14 details how QC circles are implemented.

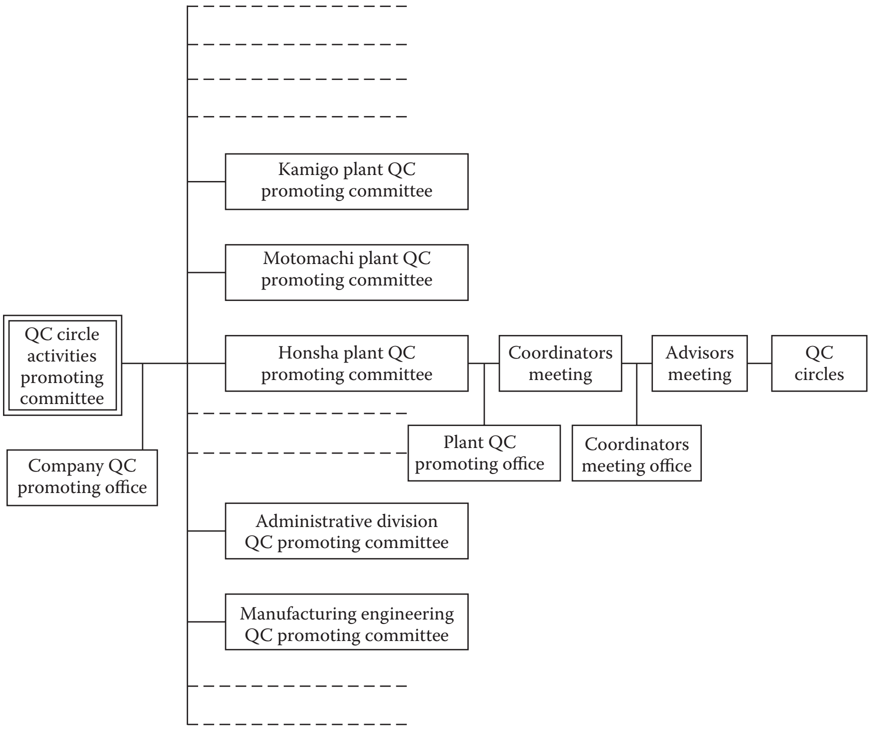


FIGURE 26.13
Organization for promoting QC circle activities.

Commendation Systems

The commendation systems at Toyota consist of three classes: topics commendation, QC circle commendation, and QC circle-Toyota prize. Each class includes various levels of awards.

The *topics commendation* awards the individual topic which was registered by each circle. When the topic has been completed, it may be awarded the *effort prize*. This is a monetary reward given each month or every other month. One-third of the topics commendations are awarded the advisor prize, and one-third of the *advisor prize* winners will be given the *coordinator prize*. These awards are given every six months.

One topic will be awarded to the plant promoting committee commendation for each workshop within the plant. Furthermore, each plant committee will recommend about four topics (responding to quality, costs, maintenance, and safety) to receive the *Gold prize* and the *Silver prize* given by the company. Because there are thirteen plants and divisions and

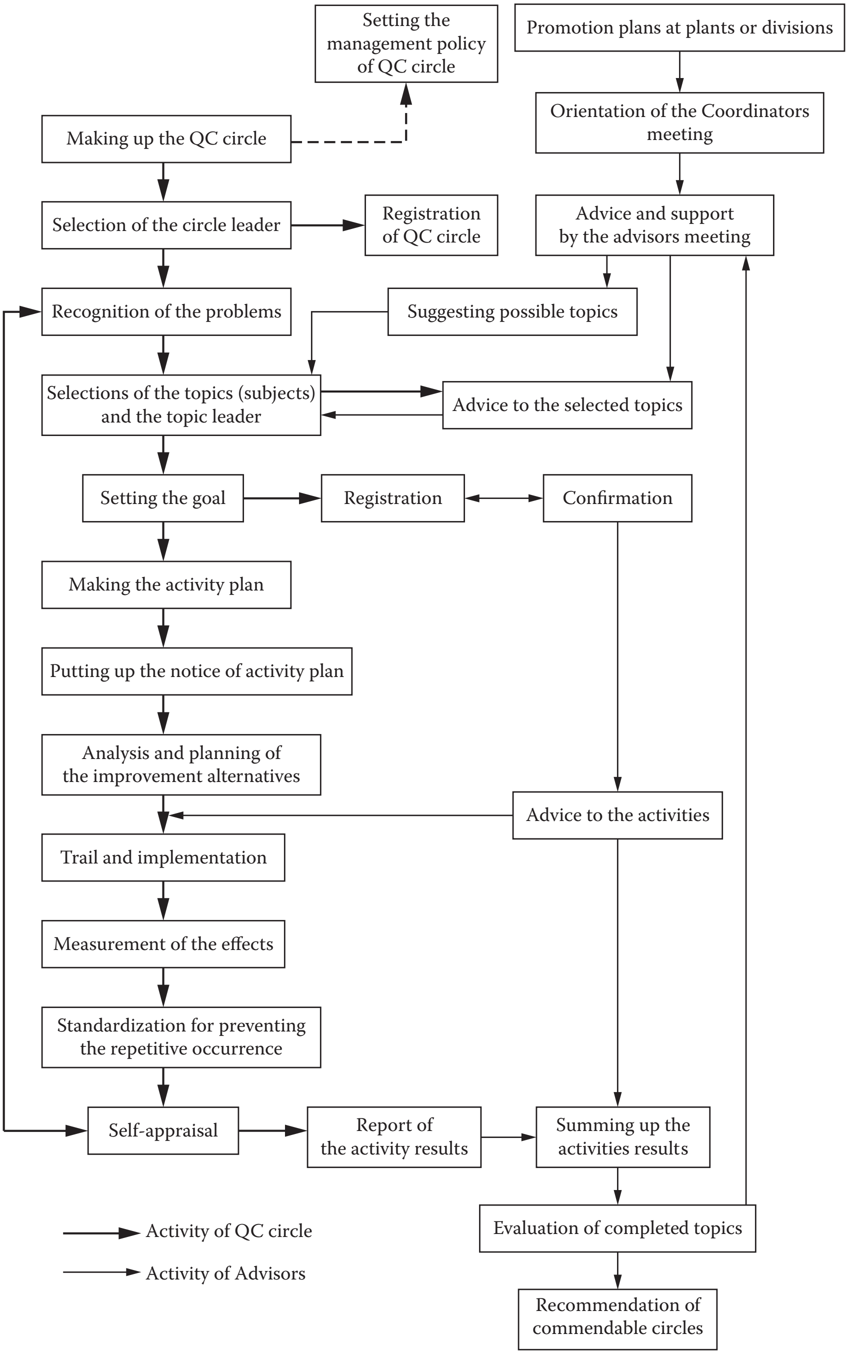


FIGURE 26.14
Promoting QC circle activities.

four topics are recommended, about 150 circles are usually awarded Gold or Silver prizes twice a year.

Awards are announced after each QC circle's presentations are made at the plant. The *QC circle commendation* awards the overall performance of a circle's one-year activities. This class of commendations also includes the advisor prize, coordinator prize, and plant committee prize.

A circle that has performed excellent activities for three years will be requested by the works manager to summarize its activities and give a presentation at the *plant-wide presentation contest*. Then, at the *first selection contest* production control managers from 13 plants and divisions will hear 13 presentations and select five circles as the final candidates for the *QC circle-Toyota prize*. These five circles must make presentations before the chairman of the company QC promoting committee and the engineering vice president. Eight circles not given the Toyota prize can still be awarded the *Excellence prize*.

Two circles out of the five Toyota prize winners will then participate in the regional QC circle contest outside the Toyota Motor Corporation. Then, if passed, they will participate in the *All-Japan QC Circles Contest*.

The suggestion system previously described in this chapter is different from the QC circle's commendation system. However, the monetary reward from the suggestion system will be given if the QC circle proposes improvement techniques. In this case, because the suggestion plan is the circle's proposal, the reward will be saved by the circle and used for its own purposes, such as a softball game or fishing contest.

Education Systems for QC Circles

At Toyota, several education programs promote QC circle activities. The following courses are held on a continuous basis:

- *Problem-solving course* for the foreman and supervisor.
- *Advisor course* for the department head and supervisor. (These two courses are also open to the supplier's employees.)
- *Trainer course* for department heads. The department heads must take this course when they are promoted.
- Various presentation contests within and without the company.
- Shipboard school which goes to Hong Kong or Formosa.
- Inspection tour for field supervisors which goes to the U.S. or Europe for three weeks.

§ 9 NEW TECHNICAL PERSONNEL SYSTEM

Labor-Management System for Toyota Shop-Floor Technicians from 1990s Onward

In the second half of the 1980s, Toyota faced problems dealing with the large numbers of factory employees it had engaged during the rapid expansion of car ownership in the 1960s. This was because, although the production department had a pyramid-type organization with a hierarchical structure including positions such as team head, group head, assistant manager, and so forth, this particular group of employees was at the bottom of the scale and there was a drastic shortage of managerial and supervisory positions into which they could be promoted as their age increased. Technical personnel were normally promoted to team head at as young as 28, with an average age of 34, while the average ages for promotion to group head and assistant manager were 43 and 48 respectively, but because of the age structure in all the Toyota factories, there was a risk that this pyramid organization would become unsustainable.

Toyota therefore decided to assess the skills of its technicians carefully and make sure it rewarded them commensurately, even if it was unable to promote them into managerial or supervisory roles (and it did so for its administrative personnel also), thereby doing its best to keep them motivated and establish a system that would enable its manufacturing personnel to give their best.

There is an excellent interview report by Osamu Katayama (1999) on labor management at Toyota in recent years. I have borrowed heavily from this report for the contents of Section 9 of this chapter.

Introduction of Technical Specialists

In 1991, Toyota created a new role, that of "technical specialist," separate from managerial and supervisory posts such as team head, group head, and assistant manager. This was split into three corresponding grades, as follows (see Figure 26.15):

Assistant-manager-class qualification: Chief Expert (CX)
Group-head-class qualification: Senior Expert (SX)
Team-head-class qualification: Expert (EX)

Qualification		Team Head, 1st Class	Team Head, 2nd Class	Group Head Class	Assistant Manager Class
Position	Managerial and supervisory	Team Head		Group Head	Assistant Manager
	Technical specialist	Expert (EX)		Senior Expert (SX)	Chief Expert (CX)

FIGURE 26.15
Review of qualifications (from February 1991).

The aim of introducing these new positions was to solve the problem of the lack of managerial and supervisory posts within the factories (in a similar way to staff positions vis-à-vis administrative management roles). The basis on which the employees' performance was evaluated was also changed in conjunction with this, from management ability to technical ability.

Specialized Skills Acquisition System

In 1991, Toyota introduced a new training scheme, which it called its Specialized Skills Acquisition System, focused on practical skills. This system focused on the actual skills required by operators and technicians, rather than on managerial and supervisory abilities as before. However, at Toyota, being "skilled" means more than simply being proficient in the technical aspects of the job. It means possessing a well-rounded body of manufacturing expertise, consisting of the following three individual skills:

1. Practical work skills (manual skills)
2. System-building skills (problem-solving ability)
3. People development skills (personnel development skills)

At Toyota, the totality of these skills is called *core competency* (the central abilities constituting the source of competitiveness).

Within these, the most important ability from the standpoint of TPS is #2, system-building skills (problem-solving ability). This is because, as explained at the beginning of the section on kaizen activities (the main topic of this chapter), TPS is based on the ability to be constantly aware of problems and continually improve the workplace.

Also, since kaizen activities consist of examining irregularities, problems, and abnormalities occurring in the workplace, tracking down their root causes, and eliminating these to achieve optimal conditions, it means being conscious of any gaps between the existing situation and the desired situation (the ideal, or the target) and continually thinking about how to close those gaps. Since this in itself is "problem-solving," the ability to do it is "problem-solving ability."

For example, let us imagine that the problem of a continually breaking lathe tool has occurred. Changing the tool to a stronger one that does not easily break would be a stopgap measure, but real problem-solving means investigating a range of hypotheses about the root causes and finding out why the tool breaks easily—whether it something to do with the way it is secured on the lathe, something to do with the lathe spindle, and so on. This is what is meant by *kaizen* in this chapter, and only technical people who can do kaizen can really be described as competent.

So, in Toyota's Specialized Skills Acquisition System, the required specialist skills are defined for each of the different crafts in each of the different job shops (assembly, paint, welding, press, machining, casting, etc.), and the technicians are graded A, B or C depending on their level of skill and are awarded a rank based on this grading. The training the technicians are given consists of on-the-job training (OJT) and off-the-job training (Off-JT). Please refer to the description of the skills ranking system at Toyota Kyushu in the final part of Section 3 of Chapter 28 for an example.

"Get-Up-and-Go Action Program"

When the technical specialist roles were introduced, some people remained dissatisfied and were unhappy at having to continue working on the line alongside ordinary rank-and-file employees despite having been promoted to a higher grade. To deal with this Toyota set up in 1995 a companywide organization of "Get-Up-and-Go Committees" and involved the factories, personnel department, and labor unions in the search for a solution.

These committees were not run arbitrarily by the personnel department; the director with responsibility for factories set them up in the beginning and made it a comprehensive project covering all the factories. The engineering works department of each factory acted as the secretariat, and the committees were staffed by section managers and assistant-manager-class personnel (Chief Experts). All technicians were also asked to complete an opinion survey. In 1997, after the committees had spent two years deliberating in this way, an initiative called the "Get-Up-and-Go Program" was launched.

This approach, in which Toyota involved its shop-floor employees and took the time to develop something which both parties could accept and

Qualification		EX 1st Class	EX 2nd Class	SX Class	CX Class
Position	Managerial and supervisory			Group Leader (GL)	Chief Leader (CL)
	Technical specialist	Expert (EX)		Senior Expert (SX)	Chief Expert (CX)

FIGURE 26.16
Revision of job titles (from April 1997 onward).

agree on, rather than using the top-down approach and having the personnel department impose it from on high, is probably one of the points that marks the company as superior.

The ultimate aim of the "Get-Up-and-Go Program" was to assess the technicians' skills and the results obtained from them.

The first thing this program did was to review the managers' and supervisors roles and positions. As Figure 26.16 shows, *head* was replaced by *leader* in the job titles. Am I the only one, I wonder, who sees this as embodying the intention to satisfy the increasing number of employees aspiring to managerial and supervisory posts by diverting their hopes in the direction of becoming technical specialists (since the title "head" strongly implies a management role)?

The image of a workplace facilitator who changes the shop floor by discovering and solving its problems is closer to that of a technical specialist than that of a manager, but Toyota probably wanted to signify this role as one in which the incumbent is expected to exercise leadership as well. The title of Group Head was thus changed to Group Leader (GL), and that of Assistant Manager to Chief Leader (CL). Meanwhile, the supervisory role of Team Head was abolished, reducing the number of management and supervisory levels from three to two. This was done because the number of people under the technicians in the teams had declined as a result of increased automation, so not as many leaders were required.

As can be seen from the top row of Figure 26.16, the titles of the technical specialists were also used as the titles of the qualifications.

The company also enabled its people to transfer readily from managerial and supervisory positions to technical specialist roles and vice versa.

New Personnel System for Technical Personnel

To round off its personnel system for technical employees, Toyota established its New Personnel System for Technical Personnel in March 1999.

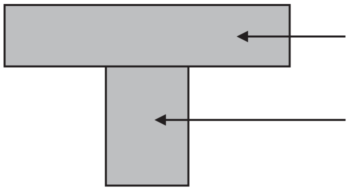


FIGURE 26.17
The type of person required by Toyota.

This had as its objectives the evaluation of technical personnel, both for developing them and for assessing them for promotion.

To begin with, "for developing them" meant for raising their capabilities. Toyota distills its basic philosophy regarding this into the following three points:

Skills Development Point 1: Draw a clear picture of the type of person required
Skills Development Point 2: Fulfill the development/evaluation cycle
Skills Development Point 3: Review the training systems for driving development

What Toyota's personnel department advocated as the "type of person required" in Point 1 was the "T-type" human being depicted in Figure 26.17. The vertical bar of the T represents excellent ability in the particular specialist field required in that person's work area, while the horizontal bar represents the ability to manage a wider range of general work, including the processes before and after the one for which the person is directly responsible.

Next, Point 2 ("Fulfill the development/evaluation cycle") means following a cycle consisting of the three processes of setting objectives, carrying out development, and evaluating the results / providing feedback, as shown in Figure 26.18. Toyota put this mechanism on a systematic footing.

Here, "setting objectives" means determining individuals' competency requirements and setting clear objectives for them, "development" means training and educating them toward the achievement of the objectives set for them in the objective-setting process, and "evaluating the results / providing feedback" means their managers evaluating their achievement of objectives, giving them feedback, and using the results in setting their objectives for the next period.

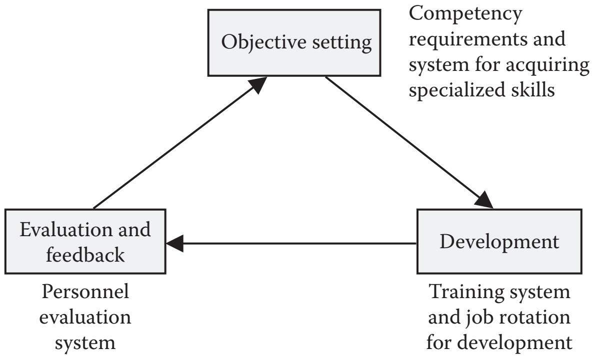


FIGURE 26.18
Toyota's Development and Evaluation Cycle.

"Competency requirements" denotes standards setting out the capabilities needed for each qualification. These summarize in the form of specific points the capabilities required for each qualification and for each job (assembly, painting, welding, machining, etc.). They are used not only for assessing people's abilities and setting their next objectives but also for appraisals such as determining their wages and promotions. For example, if a person has fulfilled all the competency requirements for the grade of expert, he or she will have satisfied the requirements for promotion to the next higher grade (senior expert). This is what Toyota's "vocational qualification system" consists of.

The final development point, Point 3 ("Review the training systems for driving development") meant changing to a training curriculum focused on acquiring kaizen ability (i.e., problem-solving ability). This is the kind of curriculum change that is often carried out by the universities and other institutions I have served on the staff of, with an eye on society's changing educational needs.

The "Discussion System" Using Development Evaluation Sheets

I will now describe what Toyota calls its "Discussion System," part of the company's new personnel system, which employs *Development Evaluation Sheets* to focus on development and assessment.

Development Evaluation Sheets (also called "Discussion Sheets") are used for conducting interviews annually between the start of the financial year in April and the end of May with all technical employees from Chief Expert grade on down. These interviews last at least thirty minutes and are carried out by the person's "post head" having a qualification one grade higher. The interviewees fill out the sheets with their own assessments of how well they have mastered each of their own competency requirements and their own assessments of their job results and efforts (how hard they have tried), and their objectives for the following year are discussed with their superior. They then recheck, between the end of August and the end of September, the results of their efforts and their level of exertion.

Each year, the superiors carry out an *absolute evaluation* to measure each individual's work results and degree of effort over the year. This is because there are objectives for the development of that person's abilities. However to appraise the person and assess them for promotion and bonuses using the sheets, a *relative evaluation* is performed.

27

Respect-for-Humanity Subsystem in the JIT Production System

§ 1 TOWARD RESPECT FOR HUMANITY BASED ON ERGONOMICS

The Japanese JIT production system is effective in enhancing the productivity of manufacturing. It can eliminate wasteful practices in the plant such as excess inventory and workforce, and it can shorten the production lead time so the company can reduce costs and provide timely products to meet market demands.

However, JIT has been strongly criticized for neglecting the human factor. For example, when excess workers are eliminated, the JIT system actually forces the remaining workers to work much harder and creates severe work strain. Therefore, human alienation can result from productivity improvements.

Since the emergence of Frederick W. Taylor's scientific management principles, conflict between productivity and respect for humanity has been recognized as a perpetual problem that needs to be addressed.

To deal with this problem, Toyota Motor Corporation's production engineering department initiated an improved respect-for-humanity system. This chapter explains Toyota's recently developed system. Also discussed are the conventional systems for human respect in the JIT system, the limitations of these systems, how the production engineering department can promote respect for humanity through facility investments, and a model for measuring the workload of each worker.

§ 2 CONVENTIONAL JIT SYSTEMS FOR RESPECT-FOR-HUMANITY REALIZATION

Toyota's production management and continuous improvement staffs have incorporated respect for humanity into the Toyota Production System in the following ways (see Figure 27.1):

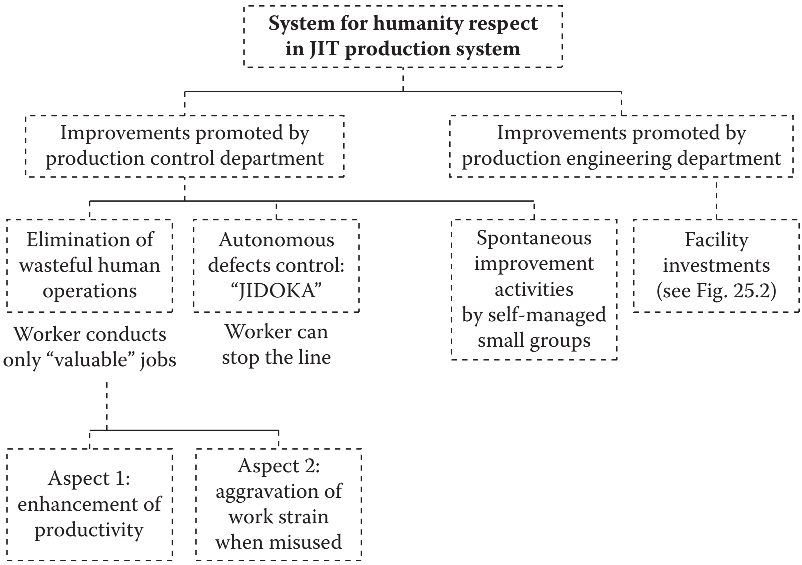


FIGURE 27.1
Respect for humanity in the JIT system.

1. All types of wasteful activities are eliminated from the plant floor. Wasteful human operations are replaced with value-added operations, thereby reducing the total standard operation time and the number of workers. Valuable jobs are given to humans, thereby improving morale while improving productivity.
2. Production lines can be stopped by workers when problems occur in the line. As mentioned earlier in this book, this practice is called *jidoka*, which is an autonomous defect control system. In the Western world, it is referred to as *empowerment*.
3. Small groups such as QC conduct continuous improvement activities and install the autonomous defect control devices. In addition, there is a suggestion system workers can use.

Eliminating wasteful activities does create some problems, however. Actions taken to increase productivity often induce hard work or work strain and, thus, human alienation. For example, often there exists a misunderstanding that improving workers' operations should be achieved by introducing as many jobs as possible into a certain takt time instead of replacing wasteful operations with value-added operations. Workers have to perform more jobs in a U-shaped line, where many types of machines are laid out. This forces workers to do harder work, which is sometimes a criticism of the Toyota Production System.

However, the Toyota Production System is evolving continuously, and it has been modified recently to substantially improve respect for humanity. These improvements are described below.

§ 3 PROCESS IMPROVEMENTS

There are two categories of facility investments that can be made to improve processes (see Figure 27.2):

1. Facility investments that incorporate automation, and
2. Facility investments that incorporate respect for humanity.

Facility Investments Incorporating Automation

Facility investments improve the productivity of humans. Installing machines helps offset the shortage of younger male workers and meets the shortened yearly labor hours Japan has required.

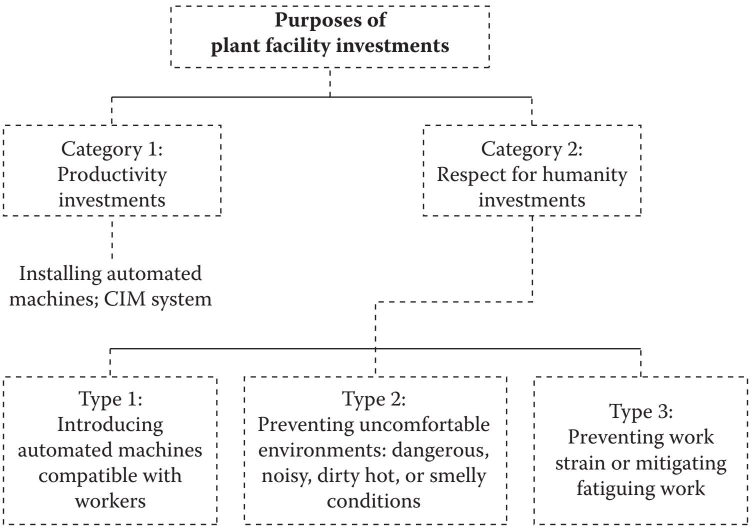


FIGURE 27.2
Categories and types of investments.

During the 1980s, this type of investment prevailed throughout Japan. Computer Integrated Manufacturing (CIM) combines innovative computer technology and the needs of labor productivity improvement. Although CIM is flexible, it does not adapt well to automobile model changes. In addition, this type of investment causes workers to feel alienated. For example, when *automated* subassembly lines are installed as separate entities and then connected to *human*-operated assembly lines, workers tend to feel they are being given orders and are being utilized by automated machines. When the machine malfunctions, workers also have to stop their jobs and wait until the machine is fixed.

Because of these problems, CIM as a facility investment became unpopular in Japan after 1990.

Facility Investments Incorporating Respect for Humanity

Since 1990, investments that incorporate respect for humanity and improve working environments have been promoted by Japanese manufacturers. The goal is to enhance respect for humanity or promote human-centeredness in a manufacturing system. Investment categories can be further divided into three types:

1. Installing machines that are compatible with workers.
2. Improving the working conditions surrounding workers. This includes eliminating dangerous, noisy, dirty, hot, or smelly conditions.
3. Avoiding work strain imposed on workers.

Worker-Compatible Machines

Automated machines located off the line are isolated from, and not accepted by, workers. Machines should be incorporated into the line and synchronously operated with workers who can control the machines. Workers should find the automated machines to be simple, highly reliable, and easily improved when necessary. For example, in the tire attachment process, the workers set the nuts and the machine fastens them automatically. In the rear-axle attachment process on the chassis line, workers load bolts on the axle and the machine fastens them. In the engine installation process, workers set the vis (screw) or nuts on the machine, and the machine fastens them.

Improving Working Conditions

Investments can be made to improve the working environment inside and outside the plant. The Toyota Motor Kyushu, Inc.–Miyata plant, referred to here as the Toyota Kyushu plant, opened in December 1992 with 2,000 workers; 1,650 of them were in the manufacturing section.

Two basic precepts were followed during the creation of the plant. The first was to coordinate the plant with the surrounding natural environment and community. For example, the exterior colors of the plant are compatible with nature. The colors are a soft blue and green on a base of grayish white. Approximately 730,000 trees were planted, including 1,500 cherry trees, and oil spills and leaks do not flow into the irrigation pond used for agricultural purposes. Inside the press plant, for instance, sound and vibration controls were installed. To absorb vibrations and sounds, a vibration-proof spring of 372 mm thickness and a soundproof cover were put on a 4,000-ton press machine. Another example of improvement entailed using dust and oil leak removal methods to reduce problems with the stamping machine.

The second precept acknowledges the role of the human as principal in car building and acknowledges respect for humans in the work environment. For example, the Miyata Assembly Park is an information corner where QC circle activities and the performance of each line are exhibited. Rest corners are places where workers from the mini-line can communicate with each other. Comfort stations (restrooms) are located conveniently around the plant. The hot corner includes vending machines, soft drinks, and a place to sit. Training corners show where all the mini-line's parts are attached to the car body. In addition, ergonomic improvements were made. The height of the parts rack was lowered to 1.5 m so workers can see throughout the plant easily. The process electric alarm board (andon) and the line proceedings control board have a rounded shape and are hung from the ceiling to make them easier to see. Air conditioners have a horizontal airflow to cover the worker's entire walking zone rather than the previous release of air to only each working point (see Figure 27.3).

Work Strain Avoidance

Avoiding work strain and preventing work overload are part of respect for humanity in the working environment, and can also lead to productivity

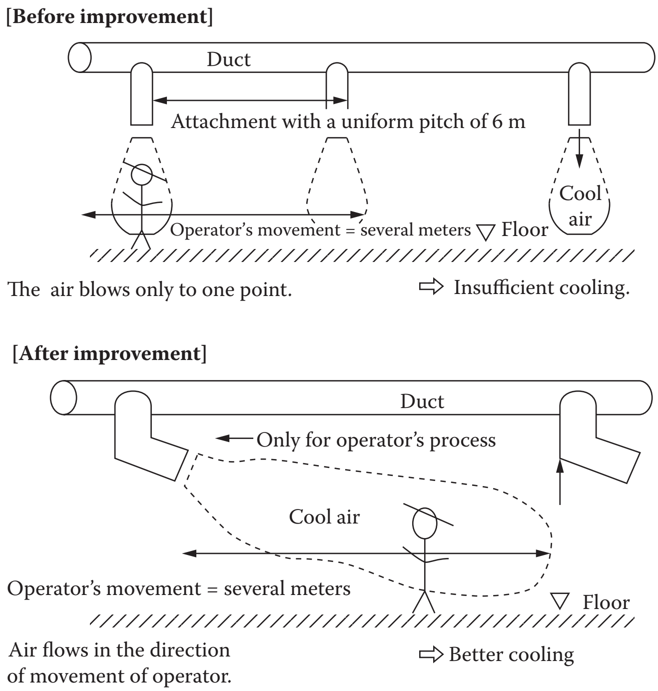


FIGURE 27.3
Assembly line cooling system.

improvements. Japan will have a shortage of younger male workers and is shortening the average yearly labor hours of workers. Japan's national target is an average of 1,800 hours per year. To meet these demands, methods are needed to ease work strain and prevent work overload. To keep the same or even increase the number of workers, the working environment needs to accommodate older and female workers.

The following is a description of Toyota Motor Corporation's practices for eliminating work strain, heavy workload, and work that caused severe fatigue in the assembly line.

The following factors influence the degree of workload and fatigue rate (see Figure 27.4):

1. Working posture
2. Handling weight of parts or tools
3. Assembling muscle power (pushing, pulling, or putting-in movements)
4. Sustaining time of operation

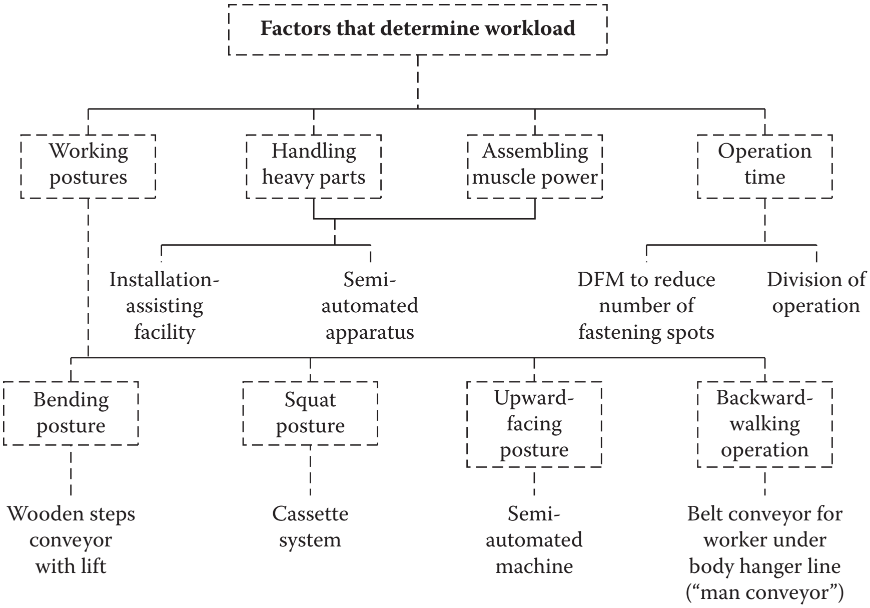


FIGURE 27.4
Improvement actions (systems) for workload determination factors.

Working Posture

Working posture most influences the fatigue rate. Working posture improvements are described below.

Bending posture. To align the vertical position of the car body to the worker's posture, Toyota installed wooden steps beside the assembly line (see Figure 27.5). This was a low-cost investment. The steps have heights of either 300 mm, 150 mm, or 50 mm depending on the differences in working postures. In the final line, the 300 mm step height is arranged for the wiper attachment station, while the door attachment station is at 50 mm. The height of these wooden steps is based on the height of the average plant worker, which may not meet all workers' needs.

Conveyor belts with a lifting device can also help with worker posture. These devices help workers easily lift a car body and automatically adjust the car body's height.

As shown in Figure 27.6, the Toyota assembly line floor moves by friction caused between the floor edge and friction roller, which is driven by a

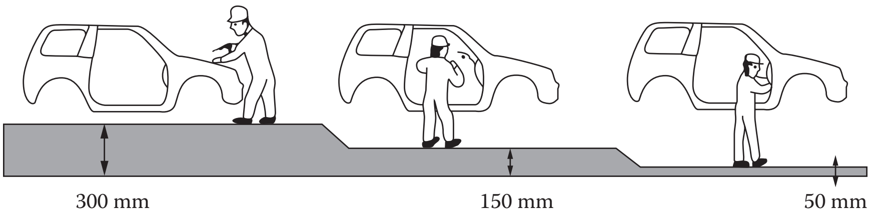


FIGURE 27.5
Wooden steps with varying heights, each suited to certain tasks performed on the car.

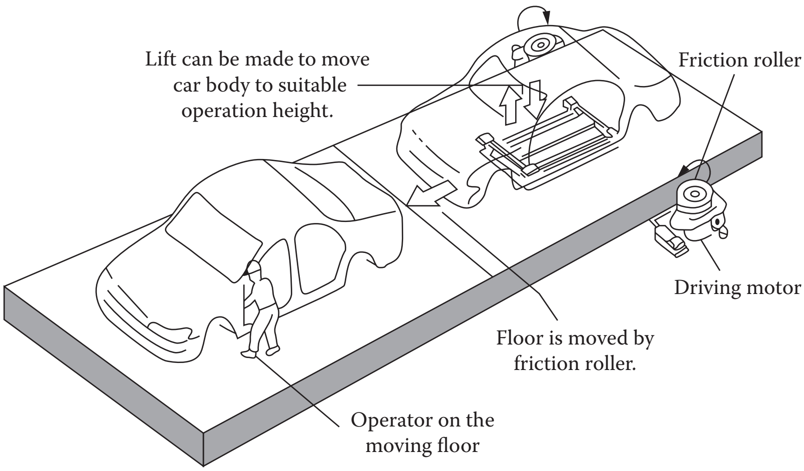


FIGURE 27.6
Friction-driven floor equipped with lifts.

motor. On this moving floor is a lift that automatically elevates a car body to a maximum height of 600 mm.

Squatting Posture. At Toyota, parts such as a door or instrument panel are called cassettes. Before cassettes can be attached, there is a pre-assembly process where cassette components are assembled outside the car body. When a cassette is attached to the body, most of the bolts are fastened automatically and only two bolts are fastened by the worker, who ensures the installation is adequate (see Figure 27.7).

Upward Facing Posture. In the Toyota chassis line, jobs requiring an upward-facing posture tax the back muscles. Therefore, fully automated or semi-automated facilities have been installed (see Figure 27.8).

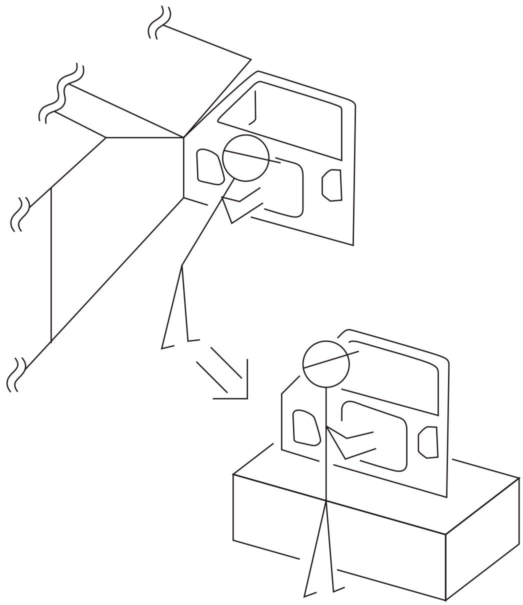


FIGURE 27.7
Cassette system to attach the door.

Backward Walking Posture. Hanger conveyors require workers to walk backwards, following the car as it moves. Installing a conveyor that moves the worker and the parts wagon helps alleviate work strain (see Figure 27.9).

Handling Weight and Assembling Muscle Power

Handling weight and assembling muscle power also affect fatigue rate and workload. Toyota has an installation assistance facility on the line where heavy parts such as instrument panels or exhaust pipes are attached to the car body. Workers do not need to carry the heavy parts from the pallet to the car body. They have only to push the hanging part into its appropriate location in the body, thus reducing arm strain. In addition, semi-automated apparatus is used to reduce the work strain associated with operations such as detaching a door or attaching a steering wheel (see Figure 27.10).

Sustaining Time of Operation

The time it takes to perform an operation is another factor affecting fatigue rate and workload. Reducing operation time can be built into the

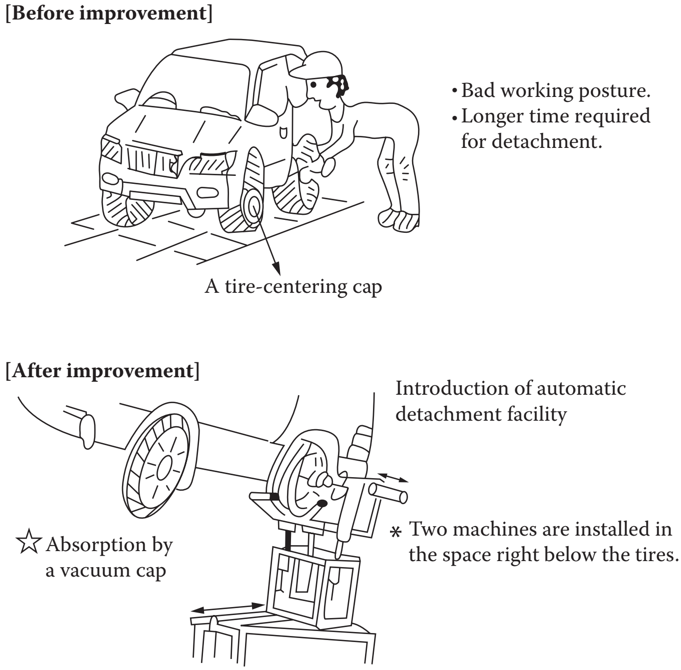


FIGURE 27.8
Fully automated facility to detach the tire-centering cap.

design phase of a car model. Design for Manufacturability (DFM) involves changing the car structure itself in the design phase so that the number of fastening spots is reduced or a new fastening structure is developed. Another way to reduce operation time is to divide operations and/or processes into many sub-operations. If the operation time (usually in seconds) is relatively long, the load or fatigue rate will be correspondingly high. Therefore, the length of each operation should be such that it does not reach its peak fatigue rate.

§ 4 NEED FOR OBJECTIVE EVALUATION OF WORKLOAD

Facility improvements often have considerable costs associated with them, and it is difficult to undertake such investment action for all the operations in the assembly line. It is necessary to objectively and quantitatively evaluate the workload of each operation for effective process improvement. To cope with worker complaints and claims that their operations

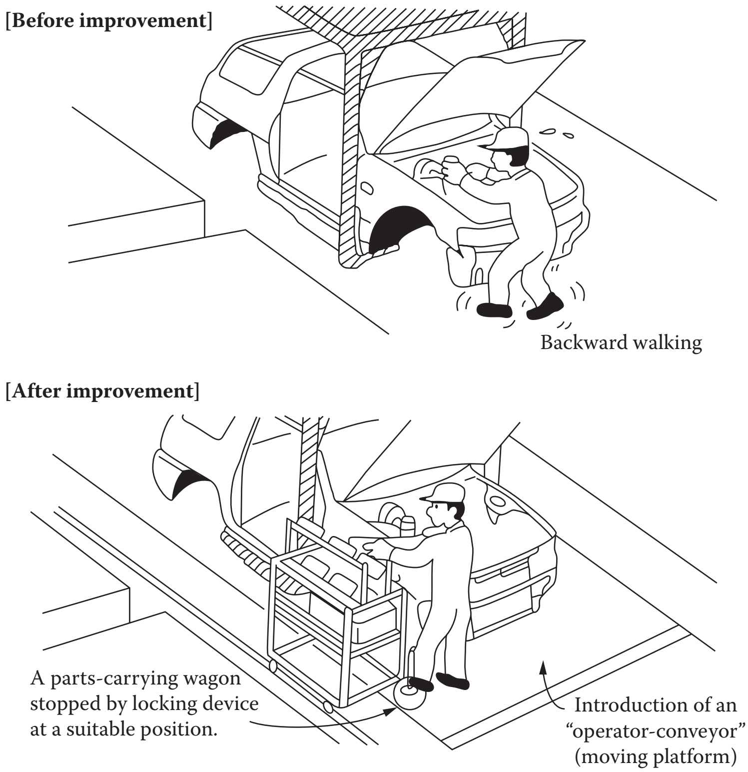


FIGURE 27.9
Moving platform for workers and parts-carrying wagon.

are much harder than others, it is necessary to have methods for objective verification of values for workload and fatigue rate. After finding those values, priorities can be assigned to operations that need to be improved.

Toyota Motor Corporation has devised such a method for finding the workload and fatigue rate values. It is referred to as the Toyota Verification of Assembly Line method, or TVAL, and is described in detail in the appendix to this chapter.

§ 5 CONCLUSION

The JIT production system is continuously evolving, and devices or improved systems are constantly being proposed to enhance human working conditions. Although the production engineering staff guides the

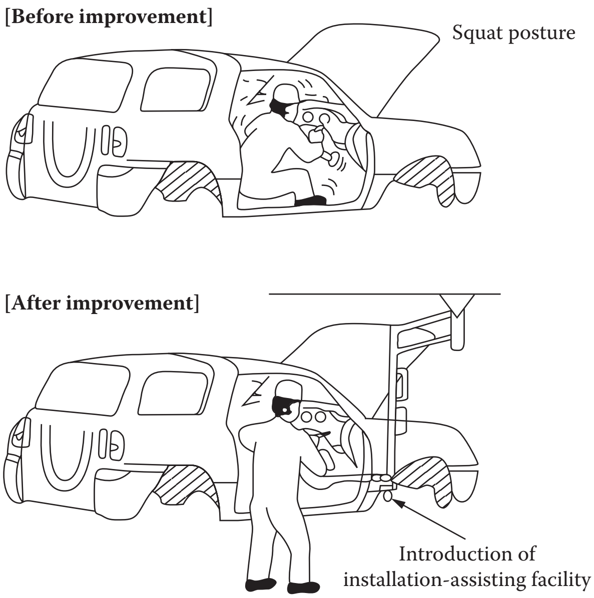


FIGURE 27.10
Assisting facility to install a heavy steering post.

promotion of improvements, workers' ideas and proposals are also important. Being involved in improving the work environment is the biggest source of a better quality of life for workers.

§ 6 APPENDIX: TVAL MODEL FOR MEASURING WORKLOAD

The Model

The Toyota production engineering department carries out various assembly line process improvements to mitigate operator workload. To determine the priority of processes for such improvements, this department must objectively evaluate the workload or fatigue rate of each process. To evaluate this information, Toyota developed the Toyota Verification of Assembly Line (TVAL) method.

The following equations are used to measure the workload or fatigue rate of each assembly line operation:

$$L = 27.03 \log t + 53.78 \log M - 48.76 \quad (27.1)$$

where

L = the physiological load or fatigue rate (%) and is the percentage to the maximum sustainable time of human operation beyond which the worker cannot continue to work under a given *intensity*.

M = the ratio of Electro-Motive Force (EMF) to its maximum value when the muscle in question is most contracted by a certain manual operation. The EMF must be measured by an EMF meter. M is a type of expression of work intensity in the definition of L.

t = sustaining time of an operation in question.

It is known that equation 27.1 will hold regardless of the position of muscle, posture of operation, and so on:

$$L = d_1 \log t + d_2 \log W - 162.0 \qquad (27.2a)$$

where W = task load. This is another expression of work intensity in the definition of L. This work intensity is determined by the handling weight, operation posture, assembling muscle power, pushing direction, and the like.

In a cycling exercise ergonomics experiment, the following values of d_1 and d_2 are well known:

$$L = 25.51 \log t + 117.6 \log W - 162.0 \qquad (27.2b)$$

where W = the load of the foot that pedals the bicycle.

Now, when the L of equation 27.1 is equivalent to the L of equation 27.2b under a certain working time, t, the following equation will hold:

$$27.3 \log t + 53.78 \log M - 48.76 = 25.51 \log t + 117.6 \log W - 162.0$$

From this equation:

$$W = 9.311\, t^{0.0129}\, M^{0.457} \qquad (27.3)$$

By using equation 27.3, the task load of cycling exercise W (equivalent to the assembly workload) can be given when the ratio of EMF M (%) of a certain operation in the car assembly line is measured by the EMF meter under a given continued time, t.

Then, the task load W_* derived by equation 27.3, when substituted into the item W on the right side of equation 27.2b, will produce the physiological load or fatigue rate L (%) of the assembly operation in question.

The above procedure for measuring the fatigue rate L is easy because it only requires measuring values M and t for each assembly operation. Such simplicity arises from the fact that equations 27.1 and 27.2b originated from previous ergonomic studies.

Applying the TVAL Model to Assembly Operations

To measure the ratio of EMF, M, under the continued time, t = 5 seconds, for various assembly operations, the assembly operations at Toyota are first classified into about 400 patterns, according to the combination of operation postures (positions), assembling muscle power, handling weight, pushing directions, and the like.

Figure 27.11 shows such patterns where the term *load* includes both muscle power (such as pushing, pulling, and fitting-in powers) and handling weight.

Push direction, etc. / Load / Posture		A Backward					B Upward		C Downward		D Forward	
		Level 1	Level 2	Level 3	Level 4	Level 5						
1.	Facing upward	31	32	35	39	45						
2.	Standing	28	30	32	34	36						
3.	Squatting	34	35	36	40	45						

FIGURE 27.11
Results of transformation to the cycling load L.

Measurements for the ratio of M_* are taken on 20 muscles in the body for each of the 400 assembly operation patterns. Applying the measured M_* to equation 27.3 gives the values W_* of cycling motion. Finally, the relative order (that is, ordinal number) of physiological load L_* for various assembly operations is compared to the actual fatigue rate workers feel in each floor operation. The result is 80 percent fitness.

Based on the values of L in Figure 27.11 (called the TVAL value) for each plant, the target value of $L = 35$ was established so that any operation exceeding $L = 35$ would no longer exist under the improvements discussed in this chapter. These improvement activities are continuing to evolve at Toyota.

Author's Comment on the Model

The following statistical problems exist in the TVAL model:

1. Multi-colinearity exists in multiple regression analysis. The partial regression coefficients of equation 27.1 are not reliable if the value M fluctuates greatly, depending on the change in the value t. The same problem occurs in equation 27.2 if the value W is remarkably affected by the change in the value t. Such correlations between M and t and also between W and t actually have been reported. However, if such correlations are small, equations 27.1 and 27.2 may be used anyway. Toyota considers that 80 percent fitness between the value L_* computed by the equations and the operators' actual fatigue level is good enough for applying their model practically.
2. Since L in equations 27.1 and 27.2 is a percentage, it takes only values ranging from 0 to 100. However, because the dependent values in the regression model should have values from $-\infty$ to $+\infty$, it would be better to convert the left side of the equations from L to $\log L/(1 - L)$.

ACKNOWLEDGMENTS

The author is indebted to these contributors for this appendix: F. Shibata, K. Imayoshi, Y. Eri, and S. Ogata. (1993). Kumitate sagyo futan no teiryo hyoka-hou TVAL no kaihatsu (Development of quantitative evaluation method, TVAL, for assembly workload). *Toyota Technical Review*, 43(1), 84–89.

The following people from the Toyota Motor Corporation provided input for this chapter in July 1994: Mr. Kiyotoshi Kato, managing director and plant manager of Toyota Kyushu; Mr. Hironori Shiramizu, director and production engineering manager of Toyota, and Mr. Hitoshi Tanaka of the Toyota P.R. department. Toyota's permission to use Figures 27.3 and 27.5 through 27.10 displayed as posters in the plants is greatly appreciated.

28

Motivational and Productivity Effects of Autonomous Split-Lines in the Assembly Plant

§ 1 WHY CAN SPLIT-LINES ENHANCE MORALE AND PRODUCTIVITY?

The purpose of this chapter is to examine the effects of splitting an automobile plant's assembly line into many *functionally diversified autonomous lines*.

A conventional assembly line is designed so that functionally different parts are assembled to a car body without rigorously classifying the parts' functions. Actually, even in the traditional assembly line of an automobile plant, there are four functionally different sections (see Figure 28.1):

1. The trim line, also referred to as the former trim line, is where the electrical parts—wire harness, instrument panel, air conditioner unit, battery, and so on—are assembled.
2. The chassis line is where the drive-train and power-train parts—engine system, exhaust pipe, and so on—are attached.
3. The final line, also referred to as the latter trim line, is where the body-related parts—bumper, front and rear glass, sheets and wheels, and so on—are affixed to the body.
4. The final inspection line is where the entire car is checked.

However, parts that are similar functionally and that should be assembled at the appropriate section of the line are not assembled to the body as expected.

They are not rigorously classified into their appropriate functional categories.

Trim Line		Chassis Line		Assembly Line
Fuel tank door detachment wire harness air conditioner unit battery instrument panel brake master cylinder, etc.	⇨	Engine exhaust pipe front and rear axle, etc.	⇨	Front and rear glass sheet door wheel bumper, etc.

FIGURE 28.1
Outline of traditional assembly line.

On the other hand, the functionally diversified autonomous line, or, in short, the *split-line*, is a mini-assembly line. Functionally similar parts from the viewpoint of car structure are rigorously grouped and assembled together. Based on this concept, the trim line, for example, may be divided into three independent lines—the wire-related line, instrument panel line, and pipe-related line.

The effects of these functionally diversified lines are twofold. Worker morale is enhanced, and productivity is improved throughout the assembly plant.

The following sections describe how Toyota Motor Corporation implemented these changes.

§ 2 PROBLEM WITH THE CONVENTIONAL ASSEMBLY LINE

In general, the traditional assembly line can also be viewed as consisting of functionally different sections. However, the number of parts and parts functions have increased remarkably in recent years. Technical innovations and expanded needs for automobile safety have increased the number of electronic and safety apparatus.

For instance, the original arrangement of Toyota's Motomachi Plant was designed for making the Publica car model during the 1960s. However, Toyota's current car model, the RAV4 (a small recreational vehicle), has ten times as many parts as the Publica. This has made it rather difficult to rigorously categorize parts according to their functional similarities, and they have been assembled haphazardly.

Also, the RAV4 uses approximately 100 times more wire harness than the Publica did. This inventory is stored in the walkway of the plant. There are many varieties of car window units and the inventory is not small, even when laid out in sequenced form. Engines and transmissions are also laid in a sequenced form, but since they are bulky, they should be assembled from the side of the walkway.

As a result, the assembly line has the following problems:

1. *A line design that neglects the functional classification of parts.* Actually, the assembly operations done in the trim line are mixed with other chassis line operations. For example, the wire-related operations are located here and there in the assembly plant. Also, the bumper, which should be attached to the body at the final line, is assembled in the former trim line due to a space shortage. It can be an obstacle for the succeeding assembly jobs and this sometimes results in damage to some parts.
2. *The elemental operations for assembling parts such as setting, nut-turning, and picking up processed parts are separated among various processes in the assembly line.* As a result, multi-skilled workers cannot understand how the tasks they are responsible for relate to each other nor can they identify their role in the whole car manufacturing structure.
3. *Difficult working conditions.* Because bulky parts like engines and transmissions are laid out in the plant walkway, the inspection line is positioned in the center of the assembly plant. Therefore, exhaust gas is emitted, water flows, noises are made, and the workspace itself is narrow. All of this disrupts the working environment. Because of the small workspace, workers have difficulty conducting materials handling so they stop the line quite often. In turn, when the line stops, the alarm light (andon) and the buzzer (which sends out an alarm sound) are turned on. However, since the noisy sounds of the inspection operation are simultaneously being emitted, they drown out the buzzer. Therefore, a louder alarm is needed so workers can hear it. To avoid these problems, the inspection operations should be separated from the assembly line and put somewhere else. This would also provide a larger workspace. However, this is just the first step.

A fundamental reorganization of the assembly line is necessary and is detailed below.

§ 3 STRUCTURE OF THE FUNCTIONALLY DIVERSIFIED AUTONOMOUS LINE

This section describes the structure of the Toyota Motor Kyushu Miyata plant (referred to as Toyota Kyushu) as a typical example of a functionally diversified autonomous assembly line.

Physical Structure of Split-Lines

Toyota's conventional assembly lines generally consist of about three or four sub-lines, each approximately 300 meters long, and all are connected together. The architectural structure of this type of plant, which has a narrow rectangular form, is depicted in Figure 28.2.

The Toyota Kyushu assembly plant, built in December 1992, is different. It is almost a square (east-west: 280 m, north-south: 265 m), and the entire assembly line is divided into 11 functional split-lines. These are based mainly on the differences in parts functions from a car design standpoint and partly on the differences of workers' operational functions (operational similarity). At Toyota, these functionally diversified lines are identified as *self-contained lines (Jiko-kanketsu rain* in Japanese). This means literally the line where everything is contained and integrated.

The layout of these mini-lines is a parallel formation, each of which is about 100 meters long. The outline of the split-lines is shown in Figure 28.3. The letter *T* represents the trim lines, the letter *C* represents the chassis

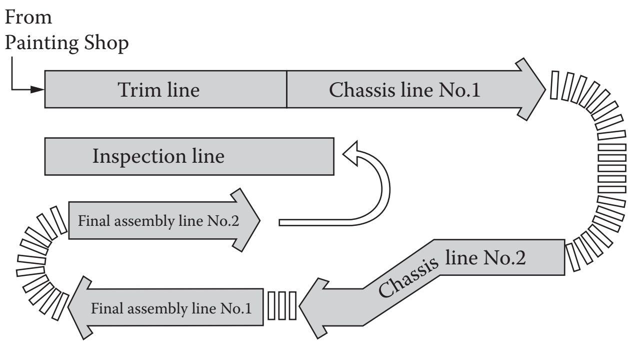


FIGURE 28.2
Layout of conventional assembly line at the Toyota Motomachi plant. (The trim line and chassis line no. 1 have now been separated and a buffer stock was put between them.)

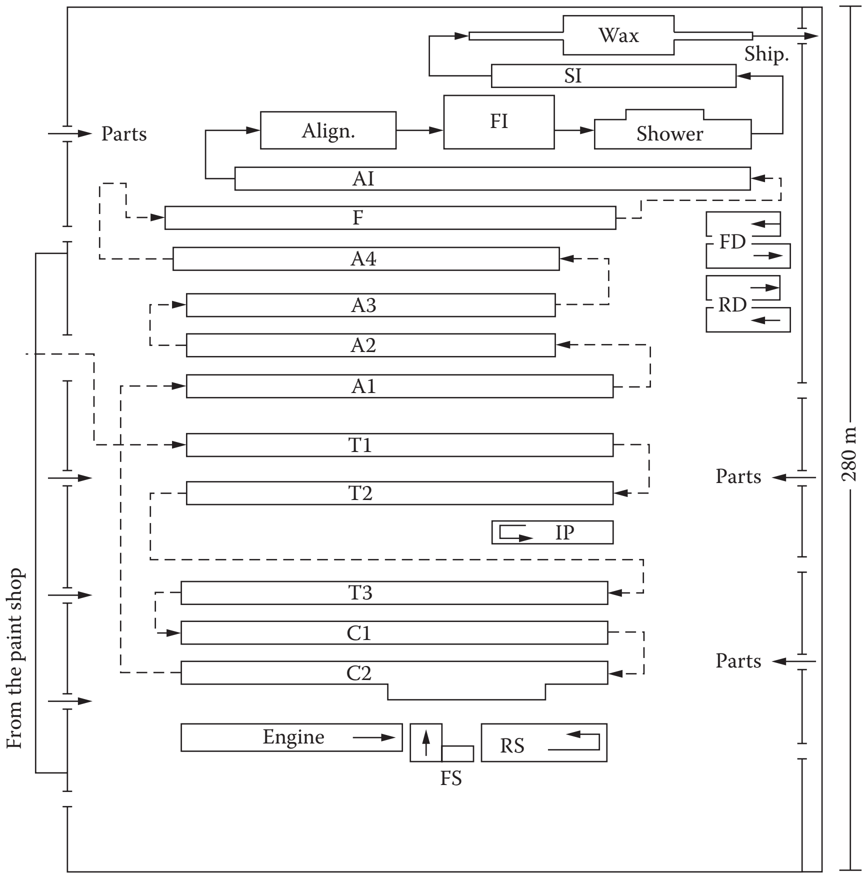


FIGURE 28.3
Layout of split-lines at Toyota Kyushu.

lines, the letter *F* represents the final lines, and the letters *AI* represent the assembly inspection line.

The total number of split-lines may vary depending on the total number of manufacturable units, the variety of cars, and the takt time. However, a line with at least 15 workstations is able to be flexible, increasing or decreasing the size of the workforce in response to demand changes.

In addition to the split-lines, this new plant has five separate subassembly lines. Three of them are for engine subassembly, front suspension subassembly, and rear suspension subassembly, all of which are located near the chassis lines.

The two other subassembly lines are for front-door and rear-door assembly. These subassembly lines typically have ten members that constitute a team.

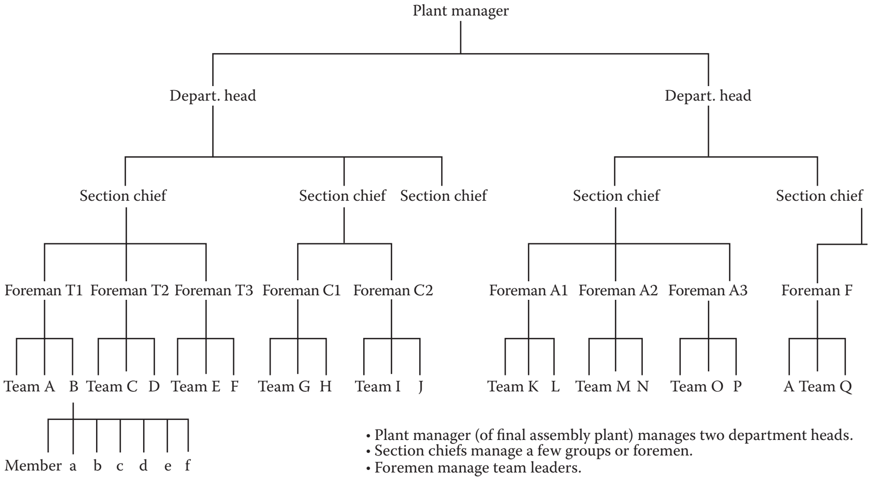


FIGURE 28.4
Personnel organization at the Toyota Kyushu plant.

Personnel Structure of Split-Lines

The personnel structure of the Toyota Kyushu assembly plant in relation to the autonomous diversified lines is summarized in Figure 28.4.

In each split-line, the functionally identical or similar jobs are grouped together. The people in the split-line work as a group, called a *Kumi* unit, which is headed by the group manager (or foreman), called *Kumi-Cho*.

The average number of members in the group is 15, although some groups can have as few as 12 members or as many as 20. Furthermore, each group consists of two or three teams, and each team has five to six members headed by a team leader called a "Hancho." In contrast, the subassembly lines (for example, the engine subassembly line) have 10 members constituting a team rather than a group. The split-line with at least 15 workstations is flexible in that the workforce can be increased or decreased depending on changes in product demand. In addition, each split-line also has at least one female worker. Although this is not surprising in the Western world, it is rare for a woman to work in the final assembly line of a Japanese automobile company.

Training of Line Workers and the Role of the Foreman

Foremen manage their assigned split-line, supervise quality control, and train their line workers. Furthermore, foremen have the authority to rotate line workers among various processes in the line.

Foremen have their own small desks beside their lines. The following information is taped on the wall in front of their desks:

1. A proceeding status table that shows how the line is achieving the day's requirements
2. An assigned process table that lists each line worker's assigned process for the day
3. A mastered processes table that shows each line worker's mastered tasks

The foremen use the assigned process and the mastered processes tables to allocate the workers' jobs or processes for the following day.

Workers can learn other job processes in their lines when they have mastered their current processes. The goal is for each worker to experience all processes in the line if possible. Since each line is confined to only one function (for example, pipe-related or wire-related tasks), workers become professionals when they have mastered all the processes of the function.

Workers may even learn a job from other lines if they so wish and also if their supervisors (team leaders and foremen) verify their current skill. A worker skilled in multiple processes is called a *multi-skilled worker*, while a worker who is versatile in various lines is called a *multi-functional worker*.

Workers are never forced to learn the jobs for many lines because the will of the worker is considered first among all things. In other words, the supervisors do not aggressively promote cross-line training.

Training Corner and the Assembly Skill Master Program

Each split-line at the Toyota Kyushu plant has its own training corner for workers. The purpose of this training corner is to make the line understandable to the workers. The T1 line (wire-related line) illustrated in Figure 28.5 is one example. All wire-related assembly parts are exhibited on the left, and the car-body is placed on the right. The team leader and foreman can easily show how parts should be assembled to the appropriate part of the car body.

Toyota also has launched an in-house training and education program called the *professional skill master program*. There are four grades of workers in the assembly lines:

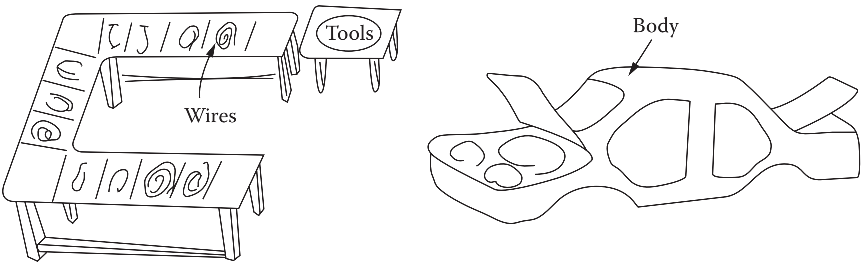


FIGURE 28.5
Training corner at the T1 (wire-related) line.

1. *Grade C* workers have a good command of all operations in their current split line. The goal for this grade is to master the operations within two years after entering the company.
2. *Grade B* workers are able to handle at least three split-lines. The goal for this grade is to master the operations within five years.
3. *Grade A* workers can do any kind of operation in any split-line in the assembly plant. There are only a small number of Grade A workers.
4. *Grade S* workers are the highest professionally skilled workers, similar to German *meisters*. As of July 1994, there were no qualified Grade S workers at Toyota Kyushu.

Names of Grade B and C workers are posted on a bulletin board to boost morale and encourage ambition. In addition, each split-line also has its own rest corner where workers can share information.

§ 4 THE MERITS OF AUTONOMOUS SPLIT-LINES

After interviewing managers at the Toyota's Kyushu and Motomachi plants, two major effects of split-lines became apparent:

1. Worker motivation
2. Productivity improvement and autonomy based on risk spreading

Worker Motivation

Split-lines affect worker motivation in many ways.

Workers Recognize Their Own Role (Jobs) in Car Manufacturing

They see their achievements as valuable and can enjoy their work lives. For example, in the new split-line, only wire-related functions in the wire-related team are grouped together. In another split-line, only the pipe-related functions are grouped together. With such groupings, workers clearly understand their own function or role in the entire car manufacturing process. Furthermore, workers become familiar with their own assigned portion of the split-line task, and they learn to recognize the tasks they are not proficient in and for which they need additional training. From the viewpoint of training, all the jobs in the split-line are easy to learn, understand, and master because they are all similar. Moreover, sharing information about jobs in the same split-line is easier among line workers.

Jobs in a Split-Line Are Easier for Workers

Although the worker must be multi-skilled and is involved in multiple jobs, these jobs are similar. The worker's posture will not suddenly change within the cycle time. Therefore, tasks are performed in a stable rhythm, which makes the job operation easier.

Some Lines Can Be Easily Prepared for Certain Classes of Workers—For Example, Female and Aged Workers

Functionally separated lines make it possible for those most suited for a line task to be assigned accordingly. This is called *just matching* at Toyota.

Group Managers Can Recognize Their Own Areas of Responsibility within the Whole Assembly Plant

The split-line is established by grouping only similar jobs. This also makes it easy for the group manager to teach workers any job in the split-line.

Workers, Group Managers, and Team Leaders Share Ownership Consciousness of the Line because of the Line's Self-Contained Character

This is why the split-line can be called an autonomous, or *decentralized*, line from the viewpoint of human collective identity.

Productivity and Autonomy Based on Risk Spreading

Split-lines affect productivity and autonomy in many ways.

The Split-Line Has a Mechanical Autonomous, or Independent, Feature Caused by Risk-Spreading Phenomena

A conventional assembly line is typically a single, long line. When trouble occurs in a line position or process, all sections stop. Split-lines do not stop automatically because other lines stop. Each can continue its operation independently for a while even when another line has stopped. This is based on the risk-spreading effect of diversified lines with buffer stocks between them. Buffer stock is kept in storage points between split-lines so each line can be active autonomously when another line has stopped, thereby maintaining the production capacity of the whole assembly plant. Buffer stocks are described in more detail later in this chapter.

Productivity Advantage as Measured by the Throughput Time of the Assembly Plant

The throughput time of an assembly plant implies the time span for a unit of product to flow from the beginning to the end of the assembly line. It is comprised of the following three components:

Throughput time = processing time + buffer stock time + plant stop time
where the processing time equals the total assembly time of all mini-lines.

For a single line system, this is equivalent to the total assembly time of all workstations in the line. Therefore, if the takt time of a unit is 2 minutes, and the standard number of workstations is 150 (which is equivalent to the average number of workers), processing time is as follows:

$$2 \text{ minutes} \times 150 = 5 \text{ hours}$$

If the line stop frequency or trouble frequency is relatively high, the throughput time of each product unit throughout the assembly plant will be shorter in the split-line system with many lines than in either a nonsplit-line system or a split-line system with only a few mini-lines. However, if the line stop frequency is relatively low, the throughput time (or total lead time) will be longer in the split-line system. Furthermore, the throughput time will be longer for split-line systems with many mini-lines than for those with few mini-lines.

Buffer Stocks between Split-Lines Require a Constant Holding Time Even without Line Stops

When there are no line stops in the assembly plant for a day, the single assembly line system has only the processing time as throughput time. The split-line system has the processing time plus the constant buffer stock time as its throughput time.

The Single Assembly Line Inevitably Must Stop When a Problem Occurs

The assembly plant with multiple split-lines does not stop as a whole if the amount of stop time at any split-line is within the buffer holding time. Therefore, the throughput time of a single assembly line increases proportionately with the increase in daily problems because of the increase in line stop time. The throughput time of the split-line system is always constant under the same condition.

The relationships between the total throughput time and the trouble frequency are illustrated in Figure 28.6. In this figure, the trouble ratio represents the number of problems occurring within a certain time span, which is also a surrogate of the average trouble frequency.

Generally, an assembly line as a whole always faces problems—defects, inability to assemble within a takt time, and so on—even under substantially improved situations. However, Toyota believes that the actual total throughput time is shorter in the split-line system than in the longer-line system when both line stop time and buffer stock time are considered. This advantage is shown in Figure 28.6 at the location indicated by actual trouble ratio on the trouble ratio axis. Note that the size of the workforce is assumed to be the same for these two systems.

The throughput time is the production lead time spent for a unit of product. The reciprocal of the throughput time, then, is a productivity measure, assuming the size of the workforce is equivalent between the two comparative systems. Figure 28.7 demonstrates the productivity advantage of the split-line system.

Example of Stop Time for the Whole Assembly Plant

For this example, we use the assembly of the MARK II car model. The Toyota Motomachi plant produced the MARK II car model using 4 separate

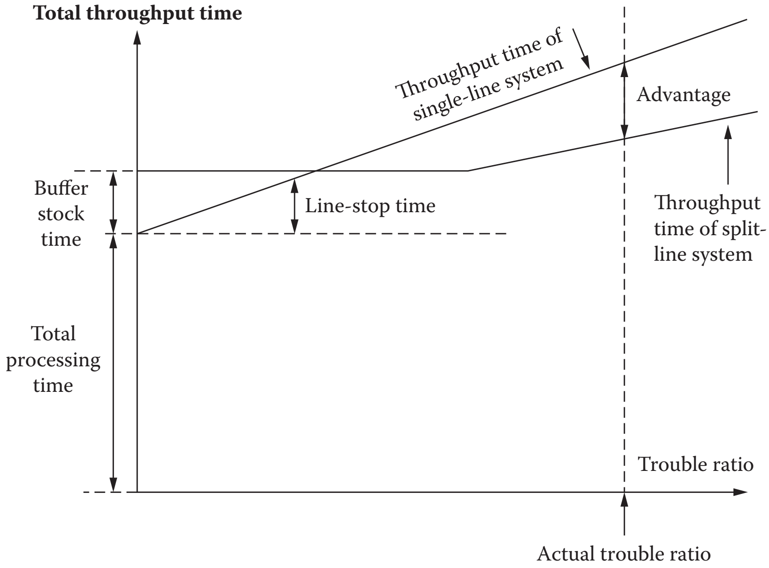


FIGURE 28.6
Relationship between total throughput time and trouble ratio.

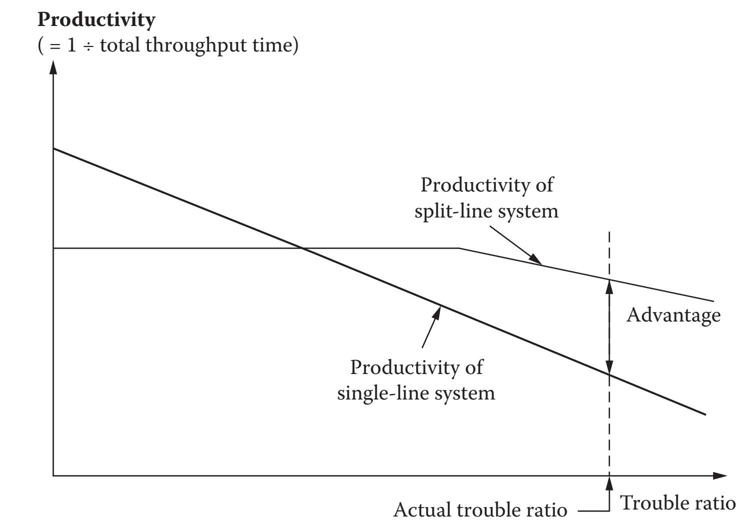


FIGURE 28.7
Relationship between productivity and trouble ratio.

lines, excluding the final inspection line. The MARK II was then moved to the Toyota Kyushu plant where 10 split-lines excluding the final inspection line were established, increasing the number of split-lines from 4 to 10.

(However, the current Motomachi plant as well as all of the other Toyota assembly plants now have about 10 split lines.)

Each of the 10 split-lines had a few units of buffer stock. As of June 1994, the buffer stock at Toyota Kyushu was actually for 5 minutes. If one split-line stopped for 5 minutes, the others continued production for at least 5 minutes. As a result, the whole assembly plant decreased its total stop time.

If each line has a stop duration of 5 minutes 6 times a day, the line stops for a total of 30 minutes during a day (6 stops × 5 minutes).

Under this assumption, consider Toyota Motomachi's previous layout. When the total number of lines was 4 and if each line stopped without any overlapping, the total stop time was still 30 minutes. The final split-line stops 6 times daily, but the stop of any other line has nothing to do with stopping the whole plant.

Now assume that the Toyota Kyushu assembly plant as a whole also stops the line the same number of times as the Toyota Motomachi plant, and also assume that each line has line stops without overlapping. Then, each split-line of the Toyota Kyushu plant has 6 × *(4 lines ÷ 10 lines)* times of line stops on average. It follows that this new plant as a whole stops for only 12 minutes:

$$6 \times (4 \text{ lines} \div 10 \text{ lines}) \text{ times} \times 5 \text{ minutes}$$

This is also due to only the final line stops. The stop time therefore decreases from 30 minutes to 12 minutes.

In this example, we assume that each problem occurs at intervals of more than 5 minutes. However, if we assumed that a certain problem occurred with intervals of less than that, not only will the troubled mini-line stop, but the problem also stops the succeeding mini-line. In these situations, the probability of line stops of all succeeding lines is increased when there are a smaller number of mini-lines as in the Toyota Motomachi plant. This phenomenon can be verified by simulating alternative split-lines, each with a different number of mini-lines.*

* Even though each mini-line had an independent problem under its own probability distribution, the probability distribution of the plant-stoppage as a whole, which would occur as the accumulation of all of the problems at each mini-line, will be the normal distribution based on the central limit theorem. Using such normal probability distribution, the mean and the standard deviation of the plant-wide stoppage-time will be measured. Then if the value of a certain plant stoppage-time is normalized applying these mean and the standard deviation, it will be possible to estimate the plant stoppage-time.

Size of Buffer Stocks

The size of buffer stock depends on the maximum normal length of each line's stop time and the takt time of the whole assembly plant. That is,

Number of stock units = Maximum normal length of each line's stop time ÷ Takt time of the whole assembly line

For example, the takt time of the assembly plant was 1.70 minutes per unit (or 102 seconds) as of July 27, 1994, and the maximum line stop time under normal conditions was 5 minutes. Therefore, for any split-line to be independent or to tolerate 5-minute stops of any other line, the line needs 3 units of buffer stock (*5 minutes ÷ 1.70 minutes)*. If the takt time is 2.5 minutes, 2 units of buffer stock *(5 minutes ÷ 2.5 minutes)* is enough for an individual line's autonomy.

Line Stop Causes

The causes of line stops determine the maximum normal time length of each line stop. Therefore, if some of the causes are eliminated or reduced and the line stabilized, the line stop time also becomes shorter, which allows a smaller number of buffer units.

At Toyota Kyushu, there can be three causes for a five-minute line stop:

1. A problem that can be solved immediately by stopping the line for one minute or less is identified as minor trouble. If the line stop time exceeds one minute, as when an instrument panel is broken, the buffer stock cannot absorb the problem. Minor line stops are described in more detail later in this chapter.
2. At the final point of each split-line, there is a quality check of the group's assembly work. When an inspection reveals a defect, it takes about two or three minutes for an action such as exchanging a pipe.
3. Each facility in a split-line is also given one minute for troubleshooting.

When all three line stops are considered together, the assumption is that each line stop is, at most, five minutes. Also, the corresponding units of buffer stock are kept at the end of the line to ensure that the succeeding split-line does not stop operation.

The Minor Line Stop

The minor line stop is often less than one minute mainly because the worker cannot complete all jobs within the takt time. This happens partly because of a lack of training about the job operation, and partly because of inappropriate task assignments among various processes in the assembly plant as a whole.

Minor Line Stop Structure

In a conventional assembly line, there is no clear-cut classification of parts into functional categories. As a result, the assembly time varies for different processes in the same line. For example, just after the engine assembly process, the interior trimming process follows. When cars with parts that require a longer assembly time are continuously introduced to the line, the line stops because workers cannot complete tasks within the takt time. To avoid this type of line stop in a mixed-model assembly line, the sequence schedule smoothes or equalizes parts assembly time or specifications.

Assembly lines that are divided into many lines, with each assigned only functionally similar processes or parts, do not have various assembly times. Giving consideration to smoothing the assembly time is no longer as necessary, although it is still part of preparing the schedule. For example, leveling still occurs for ABS brakes because that assembly creates a bottleneck.

Mental Aspect of a Minor Line Stop

In a conventional assembly line, a worker may not want to stop the line when there is a problem because it might bother other workers. However, when the line is divided into a number of sections, the worker feels more secure about stopping the line because it is much shorter and is the only one that stops. Foremen responsible for mini-lines, however, have qualms about line stops because their areas are so clearly defined by the split-line system's conveyor belt separation.

Unnecessary Inventory Eliminated as Waste

The Toyota Production System has never been a non-stock, zero inventory, or stockless system, although some writers erroneously characterize it as such. The information provided in this chapter clearly illustrates this point.

The kanban system requires a specified amount of inventory at each preceding process store so that subsequent process carriers may take the parts with their withdrawal kanban and empty parts boxes.

At Toyota, unnecessary inventory is considered waste. Toyota creates a smooth flow of production from suppliers to sales dealers by adapting their manufacturing plants to demand changes in the final market. Since buffer stocks kept in the storage points between split-lines prevent the entire assembly plant from stopping, they are quite necessary and are not considered waste.

29

Mini Profit Centers and the JIT System

§ 1 WHY DO MPC AND JIT SYSTEMS FIT EACH OTHER WELL?

Japanese manufacturing companies have been *increasingly* adopting the *mini profit center* (MPC) system. Examples include Kyocera Corporation, Sumitomo Denki Kogyo, NEC Saitama, Sony Koda, Sony Minokamo, Sanyo Kasei, Taiyo Kogyo, Maekawa Seisakusho, and 3D. Such companies are also using the JIT production system or Toyota Production System. Therefore, it seems that both systems are mutually beneficial and fit each other very well.

This chapter investigates the *advantages* that come from combining the MPC and JIT systems, and the mutual impacts on each system. For logical verification we will use the real world example of Kyocera's MPC system as one theoretical MPC model. In addition, NEC's "line-company" system, which is another type of mini profit center system, will be comparatively observed. Previous literature explains the JIT and MPC systems respectively (for MPC see Inamori [1998], [2006], Fuse et al. [2000], Monden and Hamada [1989], Kunitomo [1985], Mitsuya et al. [1999], Mitsuya [2000], and Cooper [1995]), but heretofore no research has been conducted regarding the relationships between the two. The following topics will be explored one by one:

1. Comparison and mutual extension of benefits between the JIT production system and the MPC system
2. Income statement of MPC
3. JIT production system as a prerequisite for MPC profit measurement

§ 2 COMPARISON AND MUTUAL EXTENSION OF MERITS BETWEEN JIT AND MPC SYSTEMS

The goals or effects of both the JIT and MPC systems are similar and common in many aspects, but there are also many *new* goal-items in the MPC system. Further, the means to achieve such goals in the JIT and MPC systems are also common in some areas, but there are many new means in the latter. These goals and means are summarized in Table 29.1.

Since the goals and means of the JIT Production System listed in Table 29.1 are now well known, the following sections explain mainly various aspects of the MPC system in relation to the JIT system. The mutual benefits between the JIT system and MPC will be explored in detail.

TABLE 29.1

Goals and Means of JIT and MPC Systems

	JIT System	MPC System
Small Group	QC circle or team for continuous improvements	Mini profit center for continuous improvements
Goals	Cost reduction Lead time reduction Quality assurance Respect for humanity	Profit earning Cost reduction Revenue increase Lead time reduction Quality assurance Motivation for employees
Means	1. Means for cost and time reduction: for eliminating excess inventory and workforce Pull system by kanban Production smoothing Small-lot production One-piece production U letter form layout Multi-functional worker Standard operations 2. Means for quality assurance Autonomous defect control (*jidoka*) 3. Means for humanity enhancement Small group *kaizen* activities	1. Motivating people by a single goal of profit The above five goals can be achieved only when the profit goal is pursued. 2. Delegation of larger authorities Authority for flexible exchange of workforce among MPCs Authority in the market mechanism 3. Deployment of target profit

Motivating People in an MPC through the Single Goal of Profit

The MPC system, also called the "small group profit center system," divides a company into many tiny organizational units. Each unit has about ten members and has to earn profits through their own efforts, like an independent company. This is why each unit is called a *mini profit center*.

Because the size of about ten members is the same as that of a vendor managing a personal shop in a town, management by the MPC system is a kind of firm-group management that comprises many tiny, independent companies. The leader of each MPC is similar to a president of small firm, and has to improve profit with team members through their various efforts.

On the other hand, the JIT system also utilizes continuous improvement activities by small groups called "QC circles" (Quality Control circle). The number of its members and its place as a unit in the official organizational structure are also similar to an MPC. However, the QC circle differs from the MPC in the following points:

First, while the MPC is a profit center, the QC circle is a cost center. Further, the topics or themes of a QC circle are many. While cost reduction, quality assurance, timely delivery, and quantity control are basically important for QC circles, they also conduct machine maintenance, safety, sanitary, environmental protection, moral enhancement, etc. All of these topics are handled by MPCs, too. While these goals or topics will be selected or addressed separately in QC circle activities, they could be integrated into a single goal of profit improvement in an MPC. The results of achieving these various goals will be reflected in the profit figure of an MPC. Since the contribution of efforts for achieving each topic can be very clearly shown in the profit figure, the MPC system can motivate people, stimulating their profit consciousness.

The Kyocera Corporation originated the MPC system in Japan. Kyocera was established in 1959, started to produce ceramic goods (Integrated Circuit, or IC, packages), and then expanded the business into semiconductor parts, electric parts, communication instruments, and optical precision instruments. Kyocera is now one of the leading companies in Japan in the fields of electronics and communication products, and continuously enjoys higher profits every year.

A Kyocera MPC is called an *amoeba*. Each amoeba is given only a single goal of "profit per hour" (more accurately, value-added per hour). To improve the actual figure of profit per hour, three approaches could be taken: (a) increase sales, (b) decrease costs, and (c) decrease time spent.

Among these, sales increase includes not only enhancement of the amount of sales itself but also product quality improvement and delivery-time reduction. The decrease of time implies workforce reduction and various other improvements in manufacturing methods, thereby increasing productivity.

Delegation of Larger and Wider Authority

Authority for Flexible Exchange of Workers among Various MPCs

A Kyocera amoeba is a typical MPC. An amoeba may be for one kind of product if it is organized by product variety. It can also be for a single functional manufacturing process if it is organized by manufacturing process. This is a "job-shop type" amoeba. Some may have all processes as a set, which is a "product-flow type" amoeba. Kyocera had about 13,000 employees as of the year 2000, and about 1,200 amoebas. Thus, each amoeba has 10 members on average. Although the product-flow type amoeba is consistent with a JIT layout, readers should note that the MPC also has a form of non-JIT type amoeba, which is set up for functional processes. This is because the MPC at Kyocera was initially invented and introduced when Toyota's JIT system had not been developed and become prevalent in Japan. Thus, the MPC was not necessarily linked to JIT in its original form.

The amoeba also has a common feature of flexibility in terms of member size, as any MPC does. At Kyocera when production volume is increased, the amoeba size will be expanded. If volume is decreased, the amoeba size will be shrunk. When amoeba A calls for additional workers, amoeba B will dispatch the helpers to this amoeba. Conversely amoeba B may accept workers from the other amoeba. Although both MPC and JIT systems are common in their flexible transfer of workers among centers, the JIT system transfers workers based on the instructions of the production control department, while the MPC system does this based on the individual and independent judgment of each MPC.

Decentralized Authorities of Each MPD

Various MPCs will negotiate among themselves to buy and sell any intermediate product. The items for negotiation are price (i.e., transfer price),

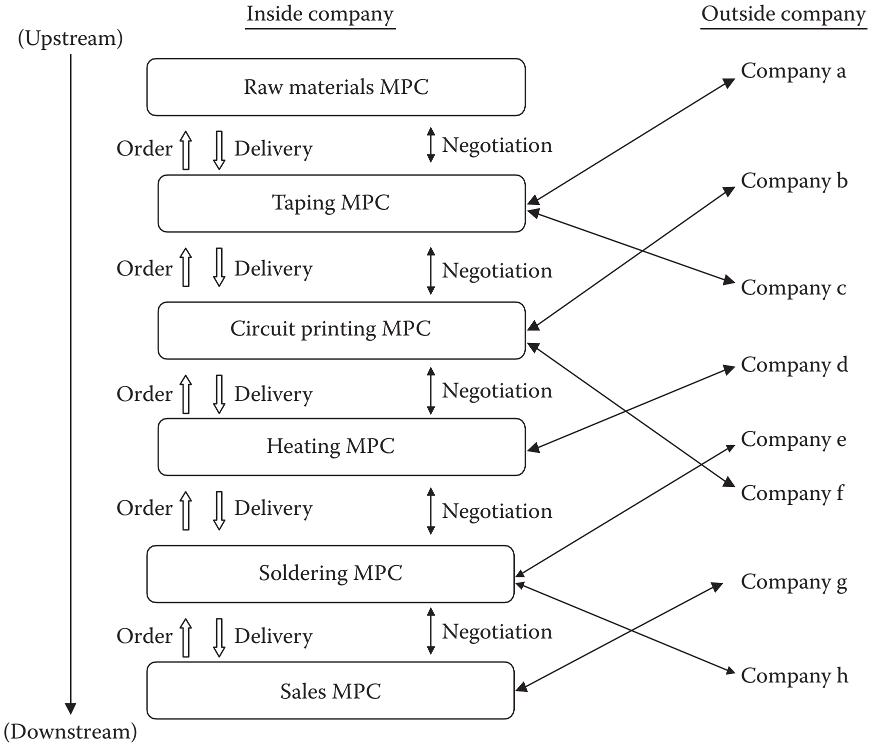


FIGURE 29.1
Competition in the MPC system. (Adapted from Kunitomo, 1985, p. 73, with revisions.)

quantity, and delivery time. In the case of the IC package, the job-shop type MPCs (based on a non-JIT type layout) are formulated at Kyocera, and they will negotiate among the processes of raw materials, taping, circuit printing, heating, soldering, and so on. (See Figure 29.1.)

Negotiation will start between the sales MPC and the soldering MPC. The orders acquired in the market by the sales MPC will be given to the soldering MPC with their price and quantity. Although the commission rate for the sales PMC is predetermined at a certain percentage level, the order price itself will be examined by the soldering MPC to see if some higher price is possible, and the sales MPC will be pushed to get a higher-price order in the market.

The following three decisions will be made by individual MPCs through negotiations. (Refer to Figure 29.1 for the following decentralized decision authorities.)

Determination of transfer-price: Orders for intermediate products will be issued from the final process MPC to the preceding MPCs continuously, where the transfer price and quantity are also negotiated. Each MPC has independent discretion in their negotiations. So their talk is not necessarily a bilateral monopoly, in which the range of price negotiation is very wide and the price would be unstable in such a wide range. As a result, a transfer price may be determined unreasonably by the stronger power figure among individual amoeba leaders. However, negotiation is not necessarily merely one to one, but usually the outside market price will be referenced and also multiple supplying processes or customer processes will enter the negotiation. Nevertheless, when no settlement is reached through independent negotiation, their boss will intervene and arbitrate a final determination.

Regarding the transfer pricing of the work-in-progress between Amoebas, Mr. Inamori says as follows: "The transfer prices will be determined from the sales price to the final customers by reversely preceding to the upstream processes. Suppose, for example, a certain ceramic products manufactured passing through various processes. The whole gross margin will be allocated from the sales price for the final customers to the final processing through the baking process, molding process, and raw materials process, step by step. The allocation of gross margin is based on the principle that almost the same amount of the "gross margin per hour" ("value-added per hour," to be explained later) will be realized in each process. However, in order to make a fair allocation of the gross margin the superior manager who is finally responsible to determine the transfer price must be familiar with the "value of each labor" for various jobs in a society. Take an electronic device, for example: what percent of gross margin is necessary for selling this product, how much will a part-timer's hourly wage be, and what rate of commissions should be paid if the same job is outsourced, etc. must be known (Inamori 2009, pp.71–72).

This method of transfer pricing is what I call the "incentive price." It is the transfer price for the fair profit allocation, rather than for the decentralized decisions based on the market mechanism. (For the "incentive price" see Monden 2011 for details.)

Selection among the vendors of intermediate products:

Competition among the supplying processes. If there are two processes that manufacture the same intermediate products, the subsequent process can decide to give an order to the "better" process in terms of quality, price, delivery time, and service. Since the selection authority is in the hands of the subsequent process, the two supplying processes must compete in their negotiations with the buying process.

Competition among the supplying process and the outside vendor. Since an MPC has the so-called right of declination, that is the right to reject offers from the in-house supplier, they can buy the intermediate product from the market. Although the decision to buy goods from the outside market is rare, its possibility will be an implicit pressure on the supplying process, which must improve their competitive edge continuously.

Authority to sell the intermediate product to the outside market. Although the selling process cannot reject the request to sell their products to the succeeding process, they can also sell some intermediate products to other companies in the market. What kinds of actions can be taken when the corporate-wide demand declines and thus no process can accept any excess workers? Under the JIT system, the excess workers (when there is no process to be able to absorb them because of a company-wide recession) will be involved in QC circle activities, conduct machine maintenance and manufacture parts that are normally subcontracted in-house. However, the decision to conduct such activities is not made by any QC circle independently, but suggested by the plant managers. On the other hand, the MPC leader can go to the outside market on his own initiative to find some orders from new customers in such idle situations, and then ask the sales department to negotiate with the customer. This is the point where the MPC system differs from JIT in profit enhancement. Cost reduction by JIT will bring profit increase under a stable sales price, even when sales volume itself has not increased. The MPC, however, can increase the sales volume itself by selling additional product to the market. This is what the JIT small group was not supposed to do.

Continuous improvement of various manufacturing methods for reducing costs: How the JIT system will extend benefits to the MPC system: Although the MPC system was initially introduced to Kyocera in a non-JIT environment, as stated above, each MPC nowadays utilizes all JIT techniques listed in Table 29.1 as their means to reduce costs under the JIT system. Therefore, the MPC system uses or incorporates the JIT system for its important improvement tools. This implies JIT is benefiting the MPC. Regarding how JIT can reduce costs, see Aigbedo (2000), Funk (1989), Miltenburg (1993), and so on.

Deployment of Target Profit

In the conventional Japanese way of corporate planning, corporate-wide goals are decomposed into various target amounts at each hierarchical level of the company. Such a goal decomposition system has been called *policy deployment* (or *Hoshin* planning or goal deployment) in Japanese TQC (Total Quality Control) or TQM (Total Quality Management). The *balanced scorecard*, which originated in the United States, also emphasizes the cause-and-effect relationship in deploying corporate objectives (see Kaplan and Norton, 1996).

Suppose the company's organizational structure is composed of the following layers:

> From corporate to/from SBU to/from division to/from department to/from section to team (which is a mini profit center)

The president's annual policy, announced in January, will be the basis for the SBU (Strategic Business Unit) manager to prepare their annual business profit plan, which includes multi-divisional annual profit plans. Then, this divisional profit plan will in turn be decomposed into the monthly profit plans of each department and sections that belong to the division in question. These monthly plans include the following schedules:

1. Monthly profit target
2. Monthly total expenses
3. Monthly value-added target
4. Monthly total labor hours
5. Monthly target value-added per hour

The section manager in turn asks each MPC leader under his guidance to prepare the same schedules as above. Each MPC's planned figures must be able to achieve the sectional value-added target given in advance. The MPC leaders must incorporate various action plans for improving not only yield-rate and production volume and reducing expenses, etc., but also for enhancing the sales revenues in their monthly plans. The monthly plans are usually prepared on a rolling monthly basis.

TABLE 29.2

Income Statement of MPC (1,000 Yen)

Total sales	A = B + C	25,000
Extra-company sales	B	5,000
Intra-company sales	C	20,000
Intra-company purchases	D	2,200
Gross contribution margin	E = A – D	22,800
Total expenses	F = a + b + c + ……… + m	11,000
Direct material costs	a	
Tools & supplies costs	b	
Subcontract processing costs	c	
Maintenance costs	d	
Power costs	e	
…	…	
Depreciation & interest costs	i	
Allocated divisional overheads	j	
Allocated plant-overheads	k	
Intra-company tech. royalty	l	
Allocated sales dep. overheads	m	
Value-added	G = E – F	11,800
Total labor hours	H = x + y + z	2,000
Regular time	x	
Overtime	y	
Allocated time of service dept.	z	
Value-added per hour (¥/h)	I = G ÷ H	5,900
Gross contrib. margin per hour (¥/h)	J = E ÷ H	11,400

Adapted from Inamori (2006) 142–143, Inamori (1998) 125, and Kunitomo (1985) 85.

§ 3 COMPUTATION FORMULA FOR MPC PROFIT

Since the MPC system treats the smallest organizational unit as a profit center, it uses a special system of profit measurement for each MPC.

Let's refer again to the amoeba system of Kyocera Corporation. An example of the income statement of a certain amoeba (in this case, an assembly process of metallic instruments to be attached to the ceramics heated in the preceding process) is shown in Table 29.2.

As shown in Table 29.2 the income measurement formula of an amoeba is as follows:

Total sales = extra-company sales + intra-company sales
Gross contribution margin = total sales – intra-company purchases
Value-added = gross contribution margin – total expenses
Value-added per hour = value-added ÷ total labor hours

The most important measure among all is *value-added per hour*, which should be maximized by the MPC. The value-added per hour can reflect the managerial efficiency of any MPC irrespective of size. Because the labor costs are not subtracted from the gross contribution margin, the gross contribution margin minus total expenses is called *value-added*, though it is not added-value in a rigorous sense since the interest costs of facilities held by the amoeba are also included in the total expenses.

The reasons why labor costs are not included in expenses when computing the value-added per hour are as follows: (1) Salaries vary among members of an MPC, and if the MPC leader knows the salary differences he may be likely to move members earning higher wage-rates out of his MPC. Or, the leader may not be able to transfer such members when necessary. (2) The labor hour figure provides enough information to measure the productivity of the MPC. (3) The MPC should create value-added, out of which they should earn their own salary. The minimum amount of value-added per hour of the MPC must be the *corporate* average wage-rate per hour (rather than average wage-rate within the MPC in question). Suppose, for instance, that the corporate average wage-rate is 2,500 yen and the value-added per hour of a certain MPC is merely 1,600 yen. Then it follows that the MPC is generously giving 900 yen (2,500 – 1,600) to the customer whenever they work one hour. In other words, this MPC is losing money at the rate of 1,600 yen per hour.

Various service costs in the plant and plant office are allocated to each MPC based on the utilization grade of such services. However, the company's central administrative costs are not allocated to the MPCs because any reasonable allocation base cannot be found. Although Activity-Based Costing (ABC) is not utilized, the costs incurred for the operations (i.e., activities) in each service department are measured and allocated to various manufacturing amoebas based on their utilization grade. The material costs in Kyocera's MPCs include all the costs of "purchases" of materials. Further, not only manufacturing costs but also sales and administrative costs are together put into this income statement. This accounting is so simple that everybody in an amoeba can understand it very easily.

To maximize the value-added per hour, sales must be maximized and expenses and labor hours must be minimized. The means for achieving such maximizations and minimizations were explained in the previous section.

§ 4 ANOTHER TYPE OF MINI PROFIT CENTER

NEC's Line-Company

Let's examine another type of mini profit center that differs from Kyocera's in its layout and profit calculation formula. NEC plants such as NEC-Saitama and NEC-Nagano are companies legally independent from NEC corporation, and make NEC's electronics products. NEC-Saitama, for example, makes cellular and PHS (Personal Handyphone System) phones. They apply the JIT production system and mini profit center system together. Each mini profit center, called a *line-company*, has about 20 members and forms a product-flow type (JIT) layout for the similar-variety series of handyphones. This layout is a kind of U-shaped form popular in the JIT production system and has no conveyer belt.

NEC's line-company has a special profit and loss statement (income statement), which contains the following cost items as expenses (Mitsuya 2000):

1. Direct labor cost and overtime cost
2. Facility costs and floor costs
3. Subcontracting costs of parts

Labor costs are computed as follows. Direct labor costs are measured by [(number of regular workers ± incremental or decremented number of workers) × average labor costs per person]. The overtime cost is calculated by [total overtime × overtime wage rate per hour]. Part timers' costs are calculated by [actual number of part-timers × labor costs per person]. As for facility costs, they will be counted as a reduction if a machine in the line is abolished. The floor costs are also counted as reduced if the line space is decreased. The subcontracting costs, for processing of parts by outside companies, are measured by [subcontracting processing cost per unit × number of subcontracting units].

However, NEC will not introduce any direct material costs (purchased parts costs) into their income statement. Thus, they introduce merely "traceable processing costs of the line" that consist of direct labor costs, direct facility costs, and direct subcontracting costs.

The sales price of each line is a kind of processing commission rate, and thus the sales amount will be [(number of completed units × standard hour per unit) × line's processing commission rate]. Since each line is a product-flow line for each series of products, the processing commission rate will be determined considering the market price of the products in question, the budgeted processing costs of the line, the break-even point volume, and so on. Therefore this sales price is a kind of target cost to be recovered by the line in question. In other words, if the line cannot realize actual processing costs that are less than this target cost, it cannot earn a positive line-profit. This price is determined by the accounting department of NEC-Saitama, not by the line company manager.

Thus, since the transfer price of NEC is determined by the accounting department, but not through the negotiation of the managers of the line-companies, and is supposed to be a kind of target cost to be achieved, this price is not a device of the decentralized decisions (or market mechanism tool). Rather NEC is using this price as an "incentive price" that motivates the line company's manager and members to be driven to continuous improvements.

The control items at NEC are similar to Kyocera and many other companies that apply JIT production systems. Profits will be earned by decreasing costs. Thus, cost reduction is the main purpose of NEC's mini profit centers. For this purpose, continuous improvement activities are conducted. (1) If the line's sales decrease the "president" of the line company in question has to reduce the number of line workers in order to earn profit. Thus, the income statement of the line will be a strong motivating tool to reduce the workforce. As is the case in Kyocera, NEC line leaders also negotiate with other line managers to transfer workers. (2) JIT promotes elimination of wasteful conveyance-time, so that unnecessary machines and floor space will be abandoned and their costs reduced. (3) Subcontractors will be replaced with internal manufacturing. They will make this decision by comparing subcontracting costs with the line's direct processing costs (excluding administrative and development costs), since the latter will not change wherever the parts were manufactured.

§ 5 LOCAL OPTIMIZATION AND GLOBAL OPTIMIZATION

The MPC concept seems to focus on the profit of the center, not the coordination of the entire manufacturing process, which is an important factor for the good use of JIT. However, both systems have some schemes for coordination or global (total) optimization. In companies like Kyocera and NEC plants, they apply MRP (Material Requirement Planning) to achieve company-wide or business group-wide coordination including parts suppliers. This is a centralized coordination based on the direct control vertical communication.

In the JIT system, the kanban system or pull system will automatically achieve total optimization during the period. Kanban is also a kind of decentralized management system, because each process can only produce as many units as withdrawn from their store by the subsequent process without knowing any other process conditions, such that all of the processes throughout the company including suppliers can produce only the necessary number of units eventually. Such autonomous coordination is made merely within a certain limited percentage of the total necessary production units determined by the MRP system.

The internal transfer price is used at both Kyosera and NEC. However, their transfer prices will not derive any rational right decisions in their decentralized decision problems such as "Make or Buy" or "Make or Subcontract" decisions by the decentralized unit (i.e., Kyosera's Amoeba and NEC's line company), because their transfer price is not based on the "incremental" cost for the company as a whole. Truly the in-house "incremental" costs (but not the "full" cost) must be compared with the outsourced prices.[1] At Kyosera the costs or daily expenses in each Amoeba include the depreciation costs and internal-interest costs of Amoeba's facilities, which are the fixed cost. Also at NEC the line company's "direct processing costs" include daily fixed labor costs and facility cost (depreciation), which are again the fixed costs.

Notwithstanding these problems, MPC's gross margin (profit) can motivate the team members of each MPC to make continuous improvements for maximizing their gross margin.

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[1] The incremental values for decentralized decisions that derive total-optimal decisions for the company as a whole are either the variable costs when the capacity for in-house manufacturing is enough (unbinding) or the variable costs plus opportunity costs when the capacity for in-house manufacturing is not enough (binding). This proposition was first found by Schmalenbach (1948) and later the same proposition was explained by Shillinglaw (1961) Chapter 22, and Horngren (1977) Chapter 2, and many other researchers in the United States.

§ 6 JIT PRODUCTION SYSTEM AS A PREREQUISITE FOR MPC ACCOUNTING

MPC Accounting Is "Cash-Basis" Accounting

The computational formula for MPC value-added is deceptively simple, almost the same as any household accounting, so that anybody in each MPC can understand it easily. An MPC will measure its value-added amount each day and each month with the assistance of the company's controller division.

It should be noted that MPC accounting will not necessarily use any traditional cost accounting in the middle of the yearly financial-accounting period, and thus they will not evaluate the materials inventory, the work-in-process inventory, and the product inventory at all during the period. Such an accounting system is equivalent to *back-flush costing* coined in the United States (for more on back-flush costing see Horngren et al. [1999, 2000]).

They regard the *cost-flow* as follows:

(a) amounts of all production factors *purchased* during a day or month
    = amounts of factors *used* during the same period
(b) amounts of all production factors *used* during the period
    = cost of goods *manufactured* during the same period
(c) costs of goods *manufactured* during the period
    = cost of goods *sold* during the same period

In the above three formulae the exceptional case is for depreciation costs of MPC facilities.

At the end of the financial accounting period, however, they have to evaluate the ending inventory of work-in-process and products, to conform to generally accepted accounting standards. It is also interesting that Kyocera is applying the so-called retail-price reduction method for evaluating these inventories. That is, the amount of inventory measured by sales price will be multiplied by a certain predetermined cost-ratio to the sales.

The MPC accounting featured above by the formulas (a), (b), and (c) could be called *cash-basis* accounting of the manufacturing sites. Such cash-basis characteristics can hold only when the ideal situation of JIT production is realized. In other words, the JIT system will bring an enormous advantage to the MPC, and it constitutes a prerequisite of MPC accounting because MPC accounting is based on the following two assumptions:

1. The lead time of a manufacturing process is very short.
2. The production factors used for the products that were manufactured during the period are all purchased the same day of the sales.

These two assumptions are well satisfied by the JIT production system, which minimizes production lead time by means of JIT one-piece production and conveyance, or small lot-size and frequent delivery, and production smoothing, etc., thus achieving formulas (a), (b), and (c) above. As a result, when the depreciation cost is excluded, all expenses accrued during the period are equivalent to the cash-outflow of the same period.

§ 7 MPC ACCOUNTING WILL PROVIDE MOTIVATION TO REDUCE EXCESS INVENTORY

According to traditional absorption costing (full cost accounting), the fixed costs are put into the product costs and become an asset on the balance sheet if unsold inventory exists at the end of the period; therefore, part of the fixed costs will not show as an expense on the income statement of the period in question. This may induce managers not to decrease excess inventory. Such adverse motivation will not be induced by the MPC accounting.

Although this demerit of absorption costing may be removed by direct costing or variable costing, MPC accounting will function much better than these costing methods in terms of inventory cutting. This is because, according to MPC accounting at Kyocera, the material costs included in the cost of goods sold are not confined to the materials of the products that were sold, but cover all of the materials purchased during the period in question. Therefore, if the MPC manager bought a material that may exceed the need for manufacturing and sales, then he must have remaining inventory at the end of the period. This ending inventory amount also appears in the MPC income statement as part of expenses, and as a result expenses will be higher and profit (value-added) will be lower compared to an MPC that purchased only the necessary amount of materials. Thanks to its unique accounting system, the MPC manager will be motivated to reduce excess material inventory.

§ 8 CONCLUSION

This chapter explains the mutual merits to be gained if the MPC system is combined with the JIT system. Table 29.1 briefly shows the goals and means of both systems comparatively. Although the goals of both systems are similar, the main goal of the MPC system is to increase profits not only by reducing costs but also by improving sales revenues, while that of the JIT system is to reduce costs (though it could *indirectly* increase profits).

Regarding the means to attain various goals, the MPC system makes good use of much wider authorities granted to MPC leaders than does the JIT system while the leader of a QC circle in the JIT system can display his authority only in the continuous improvement activities, mainly for reducing costs as a cost center leader.

The MPC leader, however, also has to be involved in continuous improvement ("kaizen") for reducing expenses, in order to improve profit (or value-added) of his MPC. In this situation, the MPC leader will have good use of all the techniques of the JIT system, and thereby each MPC can achieve a "lean" financial constitution that has no excessive workforce or inventory. This is the very advantage of JIT given to the MPC system. In other words, *the MPC system is a decentralized management system that motivates people from profit consciousness, and motivates the use of various JIT techniques to make continuous improvement for profit maximization. In short, the MPC gives a powerful driving force for implementing the JIT system, and JIT gives a powerful tool to the MPC.*

From the viewpoint of accounting, the MPC accounting system must be very simple and naïve, without doing any work-in-process evaluation unlike traditional cost accounting, so that everybody in an MPC line can understand it as easily as housekeeping accounting. This is because the main purpose of the MPC system is to motivate people throughout the company to participate in management.

Therefore, the income measurement in the MPC system must be "cash-basis" accounting like a checkbook (cash receipt and payment journal) in household accounting. In order for the income measurement to be equivalent to cash-basis accounting, a prerequisite condition of the MPC system is that it completely shorten production lead time by applying JIT. However, MPC accounting also does motivate people to remove excess inventory.

Appendix: Reinforcing the JIT System after the Disasters of 3/11/2011, Japan

Many critical comments have been made about the JIT system, saying that it was not helpful because of having *minimum* inventory when Eastern Japan experienced a major earthquake followed by a tsunami on March 11, 2011. Although the JIT competitiveness of supply and demand coordination still continues, let me write a few countermeasures to reinforce the JIT system for major earthquakes. These are the actions that many Japanese manufactures are promoting. How could we reinforce the JIT system for the whole supply-chain not to stop their flow under the sudden stoppage of partial locations in the chain? There are two main approaches.

THE FIRST APPROACH

The first approach is that for risk spreading, each auto maker should have multiple different suppliers of the same parts within their own supply chain (see Figure A.1). However, such multiple acquisitions of the same parts from the different suppliers may have the following two problems.

1. Can Toyota outsource the same components or parts from multiple suppliers?

This can be done for the first-layer suppliers, but it is sometimes difficult to do with second- or third-layer suppliers. This is especially true for high-level functional parts such as “Mi-con” (micro-computer as an electronic control device for brakes and axels, etc. of automobiles) manufactured by Renesas Electronics Corporation, which are hard to replace with other suppliers’ parts. They supply custom-made parts for each auto maker and also for each car model of each auto maker.

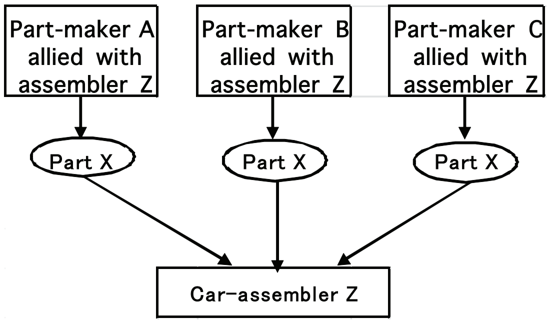

FIGURE A.1
Multiple sourcing the same parts from different suppliers of the network.

Also, Japanese assemblers in the past often reduced the number of contracted parts suppliers in order to decrease the purchased parts costs (i.e., variable manufacturing costs). When the number of contracting parts makers is reduced, the capacity-usage rate or production volume of the remaining suppliers will increase because the orders from the auto manufacturers will be made only to the remaining suppliers, so that their fixed costs per unit can be reduced and thus the parts price will be reduced.

However, such action can't be recommended from the risk-spreading viewpoint. Now is the time that we should pay for the "risk spreading costs" for the long-term sustainability of the firm.

2. ANOTHER METHOD OF RISK-SPREADING

Another method is to ask the specific supplier to establish multiple plants in various locations both in Japan and overseas, and the auto maker should acquire the parts from such multiple places at the same time (see Figure A-2).

According to this approach, even custom-parts manufacturers such as the Renesas Electronics Corporation can supply the common parts in many locations to all of the competitive auto makers at the same time. In this case Renesas has to spread their plants all over Japan for risk-spreading, and this may increase the costs due to a lower capacity-usage rate of each new plant, but its additional costs can be offset by the reduced cost under the increased production based on the common designed parts.

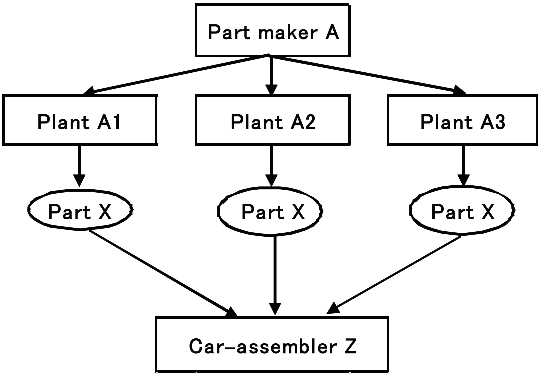

FIGURE A.2
Specific supplier establishes multiple plants in various locations.

Spreading production by transplanting the plants of suppliers to overseas

If parts suppliers transplant their manufacturing plants and design departments overseas, they can continue production without stoppage even if their domestic plants are damaged. This is particularly true for high-level functional parts such as Renesas micro-computers, which were intensively manufactured in Japan, but they began to transfer their production locations overseas.

This may weaken Japanese power because overseas production may enhance the risk of technology leakage to foreign countries, which may lower the competitive power of Japanese manufacturers. Also, since the capacity usage rate based on production centralization in Japan will be lowered, the unit manufacturing costs will increase. Furthermore, overseas production may promote industrial hollowing in domestic Japan.

The second reason this may weaken Japanese power is that even if similar parts are manufactured by multiple suppliers, the uniqueness among various suppliers will be lost when their parts are "commonized," and as a result it follows that the competition principle to make better parts than other suppliers may fail. Also there are problems to be solved regarding whether the necessary functions could be provided to the previous customers by the common parts, and regarding whether the Japanese manufacturers can keep their superior strength to the competitors of emerging countries.

THE SECOND APPROACH

The second approach is installing the "inter-network" of the supply chain rather than the "inter-firm network" of supply chain. This is what I strongly recommend. The original idea of the "Internet" of information technology was "inter-network." During the cold war in the 1960s, the United States tried to establish a solid computer communication network that could connect government, the Pentagon, and major research institutes, and could not be destroyed totally. Even if a certain communication line was destroyed by bombing, the Internet could use the other detour lines. Such uses of detour lines became possible by the development of the "packet communication" technique. The Internet consists of many independent networks, and even if part of a network is damaged, the living networks can still be connected autonomously and continue to communicate with the target address.

A single network for each automobile manufacturer is at risk in a disaster scenario, but an inter-network of supply chains that connects various rivals' supply chains can be sustainable. Even if specific portions of the network are damaged, other detour-networks can be utilized immediately (see Figure A-3).

However, this inter-network is an alliance of rival manufacturers and it may be difficult to install for important core custom-made components such as engines and missions, etc., but an agreement could be made with such an inter-network for standardized parts and modules. The aforementioned "commonization" of parts design is necessary and also useful to introduce our inter-network supply chain.

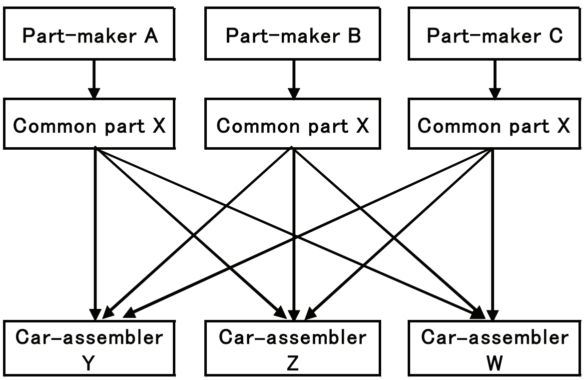

FIGURE A.3
Inter-network of supply chains.

Common design, standard design, and modules of the automobile parts

As custom-made parts are popular in the Japanese auto industry, it is difficult for the car assembler to purchase the same parts from multiple suppliers. Thus the Japanese Ministry of Economy, Trade, and Industry has begun to promote the common design of auto parts.

If the common design of parts is promoted, the auto manufacturers can utilize more than one parts supplier if they are unable obtain parts from manufacturers affected by the disaster.

Below we show a few cases of how inter-network cooperation among individual supply chains was carried out in the current Eastern Japan disasters.

CASES OF THE INTER-NETWORK SUPPLY CHAIN

CASE 1: ELECTRICITY SAVING BY TAKING SIMULTANEOUS HOLIDAYS THROUGHOUT THE AUTO INDUSTRY

The Japan Automobile Manufacturers Association has decided that the member companies will introduce simultaneous holidays every Thursday and Friday during July through September this year. Accordingly, employees will work every Saturday and Sunday during these months. This is in an attempt to reduce electricity usage during the weekday's peak of electricity usage. Big 13 auto makers who are members of this association will follow this decision. At the same time many of their indirect (office) divisions such as headquarters and R&D departments will also take holidays on the same days of the week. Further, many of the auto parts manufacturers who belong to the Japan Auto Parts Industries Association will follow this decision.

CASE 2: RIVAL AUTO MANUFACTURERS, USERS OF THE ELECTRONICS CONTROL DEVICES HAVE ALL DISPATCHED THE ALLIED SUPPORTING FORCE TO THE PLANT OF THE DAMAGED SUPPLIER

The Naka plant, located at Ibaraki prefecture of the Renesas Electronics Corporation, was stricken by the earthquakes, and at most 2,500 supporters per day have been dispatched and have been engaged in restoration of the plant, with three shifts each day.

CASE 3: INTER-NETWORK SUPPLY CHAIN OF THE PETROLEUM INDUSTRY

The supply chain networks of gasoline were also cut and stopped with this Eastern Japan disaster. Only two oil-storage places of two big oil companies continued to work. These two oil-storage places were shared by the big 5 oil companies for them to deliver the gasoline and kerosene to the affected districts.

CASE 4: THE *JAPANESE MINISTRY OF ECONOMY, TRADE, AND INDUSTRY* HAS BEGUN TO PROMOTE THE COMMON DESIGN OF AUTO PARTS

This movement will definitely promote our inter-network of supply chains.

Bibliography and References

ENGLISH LANGUAGE LITERATURE

AIAG and APICS. *Proceedings of the Production and Inventory Control Conference*, Fall 1981. Sponsored by Detroit chapter of APICS and Automotive Industry Action Group.

Aghdassi, M. and Monden, Y. 1993; 1998. Quantitative Analysis of Stocks in a JIT Multistage Productions System Using the Constant Order Cycle Withdrawal Method, In Monden, Y. 1993; 1998. *Toyota Production System,* 2nd and 3rd Editions, Institute of Industrial Engineering. Appendix 3.

Aghdassi, M. and Monden, Y. 1993; 1998. Quantitative Analysis of Lot Size in a JIT Production System Using Constant Order Quantity Withdrawal Method, In Monden, Y. 1993; 1998. *Toyota Production System,* 2nd and 3rd Editions, Institute of Industrial Engineering. Appendix 4.

Aghdassi, M. 1988. A Quantitative Analysis of Just-In-Time Production, PhD dissertation, The University of Tsukuba.

Aigbedo, H. and Monden, Y. 1996. A Simulation Analysis for Two Level Sequence-Scheduling for Just-in-Time (JIT) Mixed Model Assembly Lines, *International Journal of Production Research,* 34(11):3107–3124.

Aigbedo, H. and Monden, Y. 1997. A Parametric Procedure for Multicriterion Sequence Scheduling for Just-In-Time (JIT) Mixed Model Assembly Lines, *International Journal of Production Research*, 35(9):2543–2564.

Aigbedo, H. 2000. Just-In-Time and Its Cost Reduction Framework, in: Monden, Y. (ed.), *Japanese Cost Management*, Imperial College Press, London, UK. 205–228.

Aigbedo, H. and Monden, Y. 2001. Just-In-Time and Kanban Scheduling, Kjell B. Zandin (ed.), M*aynard's Industrial Engineering Handbook*, 5th Edition, H. B. Maynard and Company.

Akter, M., Lee, J. Y. and Monden, Y. 1999. Motivational Impact of the Type and Tightness of Target Cost Information: A Laboratory Experiment, *Advances in Management Accounting*, 8:159–171.

American Machinist. Kanbans Are Discovered, February 1981, 222.

American Production and Inventory Control Society. Pittsburgh Chapter, *Proceedings from Productivity: The Japanese Formula.* October 1980.

Ashbuen, A. 1977. Toyota's "Famous Ohno System." *American Machinist*, 120–123.

Berggren, K. 1997. *The Volvo Experience*, *Alternative to Lean Production in the Swedish Auto Industry*, Macmillan, 1993.

Berggren, K. 1993. The Volvo Uddevalla Plant: Why the Decision to Close It Is Mistaken, *Journal of Industry Studies*, 1(1): 75–87.

Bodek, N., ed. 1980. Kanban: The Coming Revolution? *Productivity News Letter* 1(7): December 1–2.

Bodek, N., ed. 1981. Productivity: Three Practical Approaches, *Proceedings of the Productivity Seminar*, held by Productivity, Inc. February 23, 1981, Chicago.

Buffa, E. S. 1984. *Meeting the Competitive Challenge: Manufacturing Strategy for U.S. Companies*, Irwin.

Butt, D. 1981. Just-in-Time in Lincoln, Nebraska: Why and How. In Bodek (1981), ibid.

Chandler, A.D. Jr. 1977. *The Visible Hand: The Managerial Revolution in American Business*, The Belknap Press of Harvard University Press.

Cho, F. and Makise, K. 1980. Toyota's Kanban, the Ultimate in Efficiency and Effectiveness. *Proceedings of American Production and Inventory Control Society*.

Cooper, R. 1995. *When Lean Enterprises Collide: Competing through Confrontation*, Harvard Business School Press, Boston, MA.

Cyert, R. M. and March, J. G. 1963. *A Behavioral Theory of the Firm,* Prentice-Hall, Englewood Cliffs, NJ.

Ellegard, K. 1995a. The Creation of a New Production System at the Volvo Automobile Plant in Uddevalla, Sweden, in: Sandberg (1995a).

Ellis, H. B. 1981. U.S. Production, Japanese Style: Kawasaki Motorcycle Plant in Nebraska, *The Christian Science Monitor*, p. 1.

Engstrom, T. and Medbo, L. 1994. Intra-Group Work Patterns in Final Assembly of Motor Vehicles, *International Journal of Operations and Production Management*, 101–113.

Engstrom, T. and Medbo, L. 1995. Production System Design—A Brief Summary of Some Swedish Design Efforts, in: Sandberg (1995), 61–73.

Engstrom, T., Jonsson, D., Medbo, L. and Medbo, P. 1995. Inter-Relations between Product Variant Codifications and Assembly Work for Flexible Manufacturing in Autonomous Groups, *Journal of Materials Processing Technology* 52:133–140.

Feigenbaum, A. V. 1961. *Total Quality Control.* New York: McGraw-Hill.

Fujimoto, K. 1980. Serving the Big Manufacturers: How to Cope with Short Lead Time and Changing Delivery Schedules, *American Production and Inventory Control Society.*

Funk, J. 1989. A Comparison of Inventory Cost Reduction Strategies in a JIT Manufacturing System, *International Journal of Production Research*, 27:1065–1080.

Galbraith, J. R. 2002. *Designing Organization: An Executive Guide to Strategy, Structure, and Process*, New and Revised Edition, John Wiley & Sons.

Hall, R. W. and Vollman, T. W. 1978. Planning Your Material Requirement, *Harvard Business Review.*

Hall, R. W. 1981. *Driving the Productivity Machine: Production Planning and Control in Japan,* American Production and Inventory Control Society.

Hamada, K. and Monden, Y. 1989. Profit Management at Kyocera Corporation: The Amoeba System, in: Monden, Y. and Sakurai M. (eds.), *Japanese Management Accounting*, Productivity Press, Cambridge, MA, 197–210.

Horngren, C., Foster, G. and Datar, M. 1997. *Cost Accounting: A Managerial Emphasis*, 9th Edition, Prentice-Hall, Upper Saddle River, NJ.

Horngren, C., Foster, G. and Datar, M. 2000. *Cost Accounting: A Managerial Emphasis*, 10th Edition, Prentice-Hall, Upper Saddle River, NJ.

Hoque, M. and Monden, Y. 2000. Effects of Designers' Participation and Evaluation Measures on Simultaneous Achievement of Quality and Costs of Product Development, *International Journal of Innovation Management*, 4(1):77–96.

Hoque, M., Akter, M. and Yamada, S. 2000. How QFD and VE should be Combined for Achieving Quality & Cost in Product Development, in: Monden, Y. (ed.) *Japanese Cost Management*, Imperial College Press.

Hoque, M. and Monden, Y. 2002. An Empirical Study on Simultaneous Achievement of Quality, Cost and Timing in Product Development, *International Journal of Manufacturing Technology and Management*, 4(1–2): 1–20.

Hoque, M., Akter, M. and Monden, Y. 2005. Concurrent Engineering: A Compromising Approach to Develop a Feasible and Customer-Pleasing Product, *International Journal of Production Research,* 43(8):1607–1624.

Hoshi, N. and Monden, Y. 2000. Profit Evaluation Measure for the Divisional Managers in Japanese Decentralized–Company—Focusing on Controllable Costs and Central Headquarters Costs, in: Monden, Y. (ed.), *Japanese Cost Management*, Imperial College Press.

Imai, M. 1986. *KAIZEN—The Key to Japan's Competitive Success*, Random House Business Division.

Japan Management Association. 1980. *Proceedings of the International Conference on Productivity and Quality Improvement: Study of Actual Cases,* Tokyo.

Japan Productivity Center for Socio-Economic Development Tokyo, 1995. *Practical Kaizen for Productivity Facilitators II.*

Kaplan, R. 1993. Research Opportunities in Management Accounting, *Journal of Management Accounting Research*, Fall. 5:1–14.

Kaplan, R. and Norton, D. 1996. *The Balanced Scorecard: Transplanting Strategy into Action*, Harvard Business School Press, Boston, MA.

Karlson, C. and Ahlstrom, P. 1966. Assessing Changes toward Lean Production, *International Journal of Operations and Production Management,* 16(2):24–41.

Kasanen, E., Lukka, K. and Siitonen, A. 1993. The Constructive Approach in Management Accounting Research, *Journal of Management Accounting Research,* 5:223–264.

Kimura, O. and Terada, H. 1981. Design and Analysis of Pull System: A Method of Multi-Stage Production Control. *International Journal of Production Research* 19(3): 241–253.

Koch, H. 1958. Zur Discussion über den Kostenbegriff, Zeitschrift für handelswirtschaftliche Forshung, 355–399.

Lawrence, P. R. and Lorsch, J. W. 1967. *Organization and Environment: Managing Differentiation and Integration.* Harvard University Press.

Lee, J. Y. and Monden, Y. 1996. An International Comparison of Manufacturing-Friendly Cost Management Systems, *The International Journal of Accounting*, 31(2): 197–212.

Lee, J. Y. and Monden, Y. 1996. Kaizen Costing: Its Structure and Cost Management Functions, *Advances in Management Accounting*, 5: 27–40.

Makido, T. 1989. Recent Trends in Japan's Cost Management Practices, Chapter 1, in Monden and Sakurai (1989), 3–13.

Miles, L. D. 1961. *Techniques of Value Analysis and Engineering*, McGraw-Hill.

Miltenburg, J. A. 1993. A Theoretical Framework for Understanding How JIT Reduces Cost and Cycle Time and Improves Quality, *International Journal of Production Economics*, 30–31:195–204.

Monden, Y. 1981. What Makes the Toyota Production System Really Tick? *Industrial Engineering* 13(1):36–46.

Monden, Y. 1981. Adaptable Kanban System Helps Toyota Maintain Just-in-Time Production, *Industrial Engineering* 13(5):28–46.

Monden, Y. 1981. Smoothed Production Lets Toyota Adapt to Demand Changes and Reduce Inventory, *Industrial Engineering* 13(8):41–51.

Monden, Y. 1981. How Toyota Shortened Supply Lot Production Time, Waiting Time and Conveyance Time, *Industrial Engineering* 13(9):22–30.

Monden, Y. 1982. The Transfer Price Based on a Shadow Price for Resource Transfers among Departments, in: Sato, Sakate, Mueller, and Radebauch (eds.), *Accounting and Information for Management Decision and Control in Japan,* American Accounting Association:55–71.

Monden, Y. 1983. *Toyota Production System*, First Edition, Industrial Engineering and Management Press, Norcross, GA.
Monden, Y. 1993. *Toyota Production System,* 2nd Edition, Industrial Engineering and Management Press. Norcross, GA.
Monden, Y. 1998. *Toyota Production System*, 3rd Edition, Industrial Engineering and Management Press, Norcross, GA.
Monden, Y., ed. 1985. *Applying Just In Time: The American/Japanese Experience,* Industrial Engineering and Management Press, Norcross, GA.
Monden, Y., Shibakawa, R., Takayanagi, S. and Nagao, T., eds. 1986. *Innovations In Management: The Japanese Corporation.* Industrial Engineering and Management Press, Norcross, GA.
Monden, Y. and Nagao, T. 1987/88. Full Cost-Based Transfer Pricing in the Japanese Auto Industry: Risk-Sharing and Risk-Spreading Behavior, *Journal of Business Administration,* 17(1–2):117–136.
Monden, Y. and Sakurai, M., eds. 1989. *Japanese Management Accounting,* Productivity Press.
Monden, M. 1993a. Japanese New-Product Development Techniques: The Target-Costing System in the Automotive Industry, *Journal of Industry Studies*, 1(1):43–49.
Monden, Y. 1993b. *The Toyota Management System: Linking the Seven Key Functional Areas*, Productivity Press.
Monden, Y., Akter, M., and Kubo, N. 1997. Target Costing Performance Based on Alternative Participation and Evaluation Methods: A Laboratory Experiment, *Managerial and Decision Economics*, 18:113–129.
Monden, Y. and Sakurai, M., eds. 1989. *Japanese Management Accounting*, Productivity Press.
Monden, Y. 1992. *Cost Management in the New Manufacturing Age: Innovations in the Japanese Automotive Industry*, Productivity Press.
Monden, Y. and Hamada, K. 1992. Target Costing and Kaizen Costing in the Japanese Automobile Companies, *Journal of Management Accounting Research*, 3:16–34.
Monden, Y. and Lee, J. Y. 1993. How Japanese Auto Maker Reduces Cost: Kaizen Costing Drives Continuous Improvement at Daihatsu, *Management Accounting* (IMA), August 22–26.
Monden, Y. 1995. *Cost Reduction System: Target Costing and Kaizen Costing*, Productivity Press.
Monden, Y. 1998. *Toyota Production System: An Integrated Approach to Just-In-Time.* 3rd Edition. Engineering and Management Press, Norcross, GA.
Monden, Y. and Hoque, M. 1999. Target Costing based on QFD, *Controlling*, Heft 11:525–534.
Monden, Y. 2000. Management Accounting for Productivity Improvement in Administrative Departments: Monden's Kaizen System, in: Monden, Y. (ed.) *Japanese Cost Management*, Imperial College Press.
Monden, Y. 2002. The Relationship between Mini Profit-Center and JIT System, *International Journal of Production Economics*, 80(2):145–154.
Monden, Y. 2011. Management Control System for Inter-Firm Cooperation: Incentive Price as Profit-Allocation Scheme, in: Monden, Y. (ed.) 2011. *Management of Inter-Firm Network*, World Scientific.
Monden, Y., Miyamoto, K., Hamada, K., Lee, G. and Asada, T. 2006. *Value-Based Management of the Rising Sun (Japan)*, World Scientific.
Monden, Y., Kosuga, M., Nagasaka, Y., Hiraoka, S. and Hoshi, N. 2007. *Japanese Management Accounting Today,* World Scientific.
Mori, M. and Harmon, R. L. 1980. Combining the Best of the West with the Best of the East-MRP and KANBAN Working in Harmony, *Proceedings of American Production and Inventory Control Society*.

Mouritsen, J. and Thrane, S. 2006. Accounting, Network Complementarities and the Development of Inter-organizational Relations, *Accounting, Organizations and Society*, 31: 241–275.

Muramatsu, R. and Miyazaki, H. 1976. A New Approach to Production Systems through Developing Human Factors in Japan, *International Journal of Production Research* 14(2):311–326.

Muramatsu, R., Miyazaki, H., and Tanaka, Y. 1980. An Approach to the Design of Production Systems Giving a High Quality of Working Life and Production Efficiency, *International Journal of Production Research* 18(2):131–141.

Muramatsu, R., Miyazaki, H., and Tanaka, Y. 1981. Example of Increasing Productivity and Product Quality through Satisfying the Worker's Desires and Developing the Worker's Motivation, *AIIE 1981 Spring Annual Conference Proceedings*, Industrial Engineering and Management Press, 652–660.

Nikko Salomon Smith Barney. 2000. Auto Manufacturers: Toyota Motor (7203-TM) *Value Chain Strategy* (1):25–32.

Okamura, K. and Yamashina, H. 1979. A Heuristic Algorithm for the Assembly Line Model-Mix Sequencing Problem to Minimize the Risk of Stopping the Conveyor, *International Journal of Production Research* 17(3):233–247.

Patchin, R. 1981. Quality Control Circles, in Bodek (1981).

Rosengren L. 1981. Potential Performance of Dock versus Line Assembly, *International Journal of Production Research* 19:139–152.

Ryan, B., Scapens, R. W., and Theobald, M. 1995. *Research Method and Methodology in Finance and Accounting*, Academic Press.

Ross, D., Wamak, J. P. and Jones, D. 1990. *The Machine That Changed the World*, Macmillan.

Runcie, J. F. 1980. By Days I Make the Cars, *Harvard Business Review*.

Sakurai, M. 1989. Target Costing and How to Use It, *Journal of Cost Management*, Summer, 39–50.

Sandberg, A. ed. 1995. *Enriching Production, Perspectives on Volvo's Uddevala Plant as an Alternative to Lean Production,* Avebury.

Shingo, S. 1981. *Study of "Toyota" Production System from Industrial Engineering Viewpoint,* Japan Management Association.

Schmalenbach, E. 1947. *Pretiale Wirtshaftslenkung, Band 1: Die optimale Geltungszahl*, Industrie-und Handelsverlag Walter Dorn GmbH.

Schmalenbach, E. 1948. *Pretiale Wirtshaftslenkung, Band 2: Pretiale Lenkung des Betriebs*, Industrie-und Handelsverlag Walter Dorn GmbH.

Schonberger, R. J. 1982. *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*, Free Press, New York.

Slack, N. and Wild, R. 1975. Production Flow Line and "Collective" Working: A Comparison, *International Journal of Production Research* 13(4):411–418.

Skiner, A. 1970. *The Wealth of Nations: Books 1–3/Adam Smith: With an Introduction by Andrew Skinner,* Harmondsworth, Middlesex: Penguin.

Smith, A. 1776 (1st ed.), 1789 (5th ed.). *An Inquiry into the Nature and Causes of the Wealth of Nations*. London: printed for A. Strahan; and T. Cadell, in the Strand, MDCCLXXXIX.

Solomons, D. 1965. *Divisional Performance: Measurement and Control*, Richard D. Irwin.

Stevenson, W. J. 1990. *Production/Operations Management,* 3rd Edition, Homewood, IL: Irwin.

Stewart, W. 1981. Productivity Measurement, in Bodek (1981).

Sugimori, Y., Kusunoki, K., Cho, F., and Uchikawa, S. 1977. Toyota Production System and Kanban System, Materialization of Just-In-Time and Respect-for-Humanity System, *International Journal of Production Research* 15(6):553–564.

Suzuki, H. 1993. *Introduction IPI Practical KAIZEN: Part I*, Japan Productivity Center.

Swamidass, P. M., ed. 2000. *Encyclopedia of Production and Manufacturing Management*, Kluwer.

Tompson, P. R. 1985. The NUMMI Production System, in: American Production and Inventory Control Society (ed.), *1985 Conference Proceedings,* 400.

Toyoda, A. 2010. Prepared Testimony of Akio Toyoda President, Toyota Motor Corporation, Committee on Oversight and Government Reform, U.S. Government, February 24.

Vogel, E. F. 1979. *Japan as Number One: Lessons for America,* Harvard University Press.

Vollum, R. B. 1987. Production Activity Control, in: White, J. A. (ed.), *Production Handbook,* 4th Edition, John Wiley & Sons: 3–194.

*The Wall Street Journal (*WSJ.com.) 2010. Crash Data Suggest Driver Error in Toyota Accidents, July 13 and 30.

Waterbury, R. 1981. How Does Just-in-Time Work in Lincoln, Nebraska? *Assembly Engineering,* April, 52–56.

Wild, N. 1975. On the selection of mass production systems, *International Journal of Production Research* 13(5):443–461.

Stevenson W. J. 1990. *Production/Operations Management,* 3rd Edition, Homewood, IL: Irwin, 354–356.

Yamada, T., Kitajima, S., and Imaeda, K. 1980. Development of a New Production Management System for the Co-Elevation of Humanity and Productivity, *International Journal of Production Research* 18(4):427–439.

Zeramdini, W., Aigbedo, H., and Monden, Y. 1988. A Two-Step Approach for Scheduling Products for JIT Mixed-Model Assembly Lines, *1998 Proceedings Asia Pacific Decision Sciences Institute Conference,* 524–526.

Zeramdini, W., Aigbedo, H., and Monden, Y. 1999. Using Genetic Algorithms for Sequencing Mixed-Model Assembly Lines to Level Parts Usage and Workload, *Proceedings of the Second Asia-Pacific Conference on Industrial Engineering and Management Systems* (APIEMS'99), Oct. 30–31, 1999, Kanazawa, Japan, 589–592.

Zeramdini, W., Aigbedo, H., and Monden, Y. 2000. Bicriteria Sequencing for Just-in-time Mixed-Model Assembly Line, *International Journal of Production Research*, 38(15):3451–3470.

JAPANESE LITERATURE

Akao, Y. 1980. Functional management and departmental management. *Hinshitsukanri* 31(5): 14–18.

———. 1978. *Toyota, Its True Nature*. Seki Bun Sha.

Aoki, M. 2007. *Full Illustration of the Systems of Toyota Production Plants,* Nihon-Jitsugyou Shuppansha.

Aoki, S. 1981. Functional Management as Top Management-Concepts at Toyota Motor Co., Ltd. and Its Actual Execution. *Hinshitsukanri*. 32(2): 92–98; 32(3): 66–71; 32(4): 65–69.

Aona, F. 1982. *Toyota's Sales Strategy*. Diamond.
Arita, S. 1978. A Consideration of the Effect of Smoothed Production on the Reduction of Work-in-Process Inventory. *Kojokanri*. 24(13): 109–115.
Ban, S. and Kimura, O. 1986. Toyota's Manufacturing Departments: Complete Implementation of Basic Principles and Incorporation of Flexibility. *JMA Production Management*, October, 13–22.
Cho, F. 2010. Inventory Reduction was not Compromised between Manufacturing and Sales Departments Before, *Nikkei Economic Journal,* June 1.
Delphys IT Works, ed. 2001. *Toyota and Gazoo: Strategic Business Model as a Whole*, Chuoh Keizaisha.
Endo, K. 1978. Toyota System-Image and True Nature. *Kojokanri*, 24(13): 141–145.
Fujimoto, K. 1983. *American Kanban System: Plant Revolution through MPR*, Diamond-sha.
Fujimoto, T. 1997. *Evolution of Production System*, Yuhikaku.
Fujimoto, T. 2004. *Japanese Manufacturing Philosophy*, Nihon Keizai Shinbunsha.
Fujimoto, T., Nishiguch, T. and Ito, H. 1998. *Readings of Supplier System: Forming the New Inter-Firm Relations*, Yuhikaku.
Fujita, A. 1978. Merits and Faults of Toyota Production System. *Kojokanri*, 24(13): 120–124.
Fukunaga, M. 1986. Control System for Corresponding to Multi-model Production. *IE Review*, 27(1).
Fukuoka, Y. 1990. The New ALC System at Toyota, in: Fujitsu Co. (ed.) *Proceedings of Fujitsu CIM Symposium in Osaka*, pp. 44–71.
Fukushima, S. 1978. Toyota's Parts-Integration from Product-Planning Stage. *IE*, March: 58–63.
Furukawa, Y. 1981. System Theory of Quality Control. *Operations Research*, August: 443–450.
Fuse, M., Miyoshi, K., and Higuchi, H. 2000. Line-Company System of Sumitomo Denko, *Kojokanri*, 46(11).
Harazaki, I. 1981. Multi-Functioned Worker Role in Many Varieties, Short-Run Production. *Kojokanri*, 27(2): 86–87.
Hasegawa, M., Tanaka, T., and Sugie, K. 1981. In-Process Quality Control for Each Job Position Realized Zero Delivery Claim at Akashi Kikai Co. Ltd. *Kojokanri*, 27(1): 15–24.
Hashimoto, F. 1981. Assignments to Realize the Unmanned Plant from Software Viewpoints. *Kojokanri*, 27(4): 6–36.
Hatano, T. 1982. Vendor's Online Delivery System Correspond to the Line Balanced Production. *IE*, January: 30–34.
Hattori, M. 1981. Production System Adaptable to Changes—An Example of Nippon-Denso's Mixed-Model High-Speed Automatic Assembly Line. *IE*, January: 22–27.
Hayashi, Y. 1987. *Ningen Kougaku (Ergonomics)*. Nihon Kikaku Kyokai.
Hino, S. 2002. *Research in Toyota Management System*, Diamond-sha.
Hirano, H. 1983. Why Is the Kanban-MRP Combination Useful Today? *Kojokanri*, 29(1).
Hirano, H. ed. 1990. *5S Guidance Manual*, Nikkan-Kogyo Shinbunsha.
Hirano, H., ed. 1984. *Handbook of Factory Rationalization*. Nikkankogyo Shinbun-Sha.
Hirano, H. 1989. *100 Q&A for JIT Introduction*, Nikkan Kogyo Shinbun.
Hitomi, K. 1978. A Consideration of the Toyota Production System. *Kojokanri*, 26(13): 116–119.
———. 1979. GT System for Many Varieties, Short-Run Production. *Kojokanri*, 25(18): 111–119.

———. 1987. *Text Book of Production for Many Variety with Short Run*. Nikkankogyo Shinbun-Sha.

Honda, J. 1988. 5S *Animation: Seiri, Seiton, Seiketsu, Seiso, and Shitsuke*. Nikkankogyo Shinbun-Sha.

Honjo, J. 1988. *Toyota's Marketing Power: Secret of Its Strength*. Nisshin-Houdo.

Iijima, A. 1981. Implementation of Company-Wide Quality Control at Toyota Auto Body Co., Ltd. *Hinshitsukanri*, 32(1): 20–26.

Ikari, Y. 1981. *Comparative Study, Japan's Automotive Industry—Production Technology of Nine Advanced Companies*. Nippon Noritsu Kyokai.

———. 1983. *Development No. 179—The Road to Corolla*. Bungei-Shunjie.

———. 1985. *Toyota vs. Nissan: The Front of New Car Development*. Diamond.

Ikeda, M. 1980. *Informal History of Toyota—Sakicht, Risaburo, Kiichiro, Ishida, and Kamiya*. Sancho Co., Ltd.

Imai, K., Itami, H. and Koike, K. 1982. *Economics of Internal Organization*, Toyo Keizai Shinposha.

Inamori, K. 1998. *Practical Learning of Kazuo Inamori: Management and Accounting*, Nihon Keizai Shinbunsha.

Inamori, K. 2006. *Amoeba Management,* Nihon Keizai Shinbunsha.

Ishikawa, K. 1981. *Japan's Quality Control*. Nikka Giren.

Ishikawa, K. and Isogai, S. 1981. Introduction and Promotion of TQC: Functional Management. *Hinshitsukanri*, 32(11): 88–96.

Ishitsubo, T. 1978. Reduction of the Die-Change Time for the Washer Outside-Frame. *Kojokanri*, 24(7): 40–44.

Itami, H. 1982. *Beyond Japanese Management*. Toyokeizai Sinpo Sha.

Ito, T. 1979. Complete Change in Thinking Lets Arai Seisakusho, Ltd. Promote Production Smoothing. *Kojokanri*, 25(8): 157–163.

Iwai, M. 1981. How the No. 1 Improvement Proposers Are Making Their Ideas. *President*, December: 146–166.

Iwamuro, H. 2002. *Cell Production System*, Nikkan Kogyo Shinbunsha.

Japan Management Association and Monden, Y. 1986. *New Edition: Toyota's Factory Management*. Japan Management Association.

Just-In-Time Production System Research Workshop, ed. 2004. *Just-In-Time Production.* Nikkan-Kogyo Shinbunsha.

Kanpo. 1982. Questions by Ms. Michiko Tanaka to the Ministers of State. *Proceedings of the House of Representatives*, no. 4. October 7: 62–66.

Katayama, O. 2002. *How Did Toyota Cultivate the Strongest Employee*? Shodensha.

Kato, J. 1982. Introduction of Robotics to the Manufacturing Floor—Japanese Industrial Relations Will Not Break. *Nihon Keizai Shinbun*, May 3.

Kato, N. 1984. Mixed Production of Agricultural Four Wheel Tractor. *Kojokanri*, 30(11).

Kato, T. 1981 and 1982. Revolutional Management of Punchpress Process—From the Introduction of Kanban System to the Scheduling by Microcomputer (1–14). *Press Gijutsu*, 19(1–2, 4–13); 20(1–3).

———. 1981. New Production Management for the Punchpress Process. *IE*, December: 77–80.

Kawada, S. 2004. *Toyota System and Managerial Accounting*, Chuoh Keizaisha.

Kawaguchi, H. 1980. Visual Control at Toyoda Gosei's Cutting Operation Process. *Kojokanri*, 26(13): 26–33.

———. Basic Promotion Method of Toyota Production System. 1990. In: Chubu Industrial Engineering Association (ed.) *Seminar Text of Toyota Production System Practice*. November: 11–20.

Kawamura, T., Niimi, A., Kubo, S. and Katsuhara, T. (1993). Human-centered design of assembly line in the coming age. *Toyota Technical Review*, 43(2), 87–91.

Kawashima, Y. 1980. Overseas Strategy of Honda, a Pioneer Company Which Extended to America. *Kojokanri*, 26(7): 40–47.

Kestler, A. 1983. Translated by Tanaka, M. and Yashioka, Y. *Holonic Revolution*. Kosakusha.

Kikuchi, H. 1978. Recent Problems Concerning the Subcontract Transactions. *Kosei-Torihiki*. November: 11–18.

Kobayashi, I. 1978. Remarkable Reduction Time and Workforce by Applying the Single-Setup at Machining and Pressing Operations. *Kojokanri*, 24(7): 45–52.

Kohno, T. 1987. *Strategy for the New Product Development*. Diamond.

Kojima, A. 1980. Productivity Arguments in the United States (1 and 2). *Nihon Kezai Shinbun*, June 10–1.

Kojokanri, 1978a. Standard Operations and Process Improvements at Toyoda Gosei Co., Ltd. 24(13): 70–82.

———. 1978b. Multi-process Holdings at the Casting Processes of Aisin Seiki Co., Ltd. 24(13): 83–88.

———. 1980. A Case of the Auto-Parts Maker Who Realized Small Lot, Short-Cycle Delivery via MRP. 26(12): 61–67.

———. 1981a. Production Revolution at Reviving Toyo Kogyo Co., Ltd. 27(6): 17–37.

———. 1981b. Practices of the Small Lot, Mixed-Model Production System-Seven Cases. 27(7): 17–64.

———. Special Issue, 1994. This Is the "New" Toyota Production System, *Kojokanri*, 43(4).

———. Special Issue, 1995. Production Innovation Movement of All NEC, *Kojokanri*, 40(14).

———.Special Issue, 1998. Why Does Single-Person Production System Pay? Kojokanri, 43(4).

Kotani, S. 1982. On the Sequencing Problem of the Mixed Model Line. *Japan Operations Research Society Spring Conference Proceedings*. pp. 149–150.

Kotani, S. 2008. *Understandable Toyota Production System from Theory to Techniques*, Nikkan-Kogyou Shinbunsha.

Kotani, S. 2009. *"Kaizen Capability" Cultivated by Toyota Production System*, Nikkan Kogyo Shinbunsha.

Koura, K. 1981. Quality and Economy. *Operations Research*, August: 437–442.

Kubo, N. 1979. Production Control at Yammer Diesel Co., Ltd. Synchronizes with the Master Schedule. *Kojokanri*, 25(8): 149–156.

Kumagai, T. 1978. Characteristics of Toyota Production System. *Kojokanri*, 24(13): 152–157.

Kunitomo, 1985. Kyocera's Amoeba Management, Paru Shuppan.

Kurabayashi,T T. 1988. Line Profit Management of Nagano Kenwood, *Kojokanri*, 43(4).

Kuroiwa, M. 1995. Efforts to Upgrade Parts Distribution Based on the Toyota Production System, *ICLS95* B-3, 117–22.

Kurokawa, F. 2008. *Automobile Industry Strategy of 21st Century*, Zeimukeiri Kyoukai.

Kuroyanagi, M. 1980. Visual Control of Aisan Kogyo's Machining Line. *Kojokanri*, 26(13): 15–25.

Kusaba et al. 1981. Report of the 11th Overseas Quality Control Observation Team. (2) *Hinshitsukanri*. 32(10): 58–64.

Maeda, S. 1982. FMS without Failure—A Case of Tokyo Shibaura Electric Co., Ltd. *Nihon Keizai Shinbun*, August 9.

Makido, T. 1979. Recent Tendency of Cost Management Practices in Japan. *Kigyo Kaike*, March: 126–132.

Masuyama, A. 1983. Idea and Practice of Toyota's FMS. In: Ohno, T. and Monden, Y. (eds.) *New Development of Toyota Production System*. Japan Management Association. 13–27.

Matsumae, H. 1978. Toyota Production System and VE. *Kojokanri*, 24(13): 149–152.

Matsuura, M. 1979. *Secret of Toyota's Sales Power*. Sangyo Noritsu Tanki Daigaku Publishing Division.

Matsuura, T., Ojima, T., and Ohmori, K. 1978. Single-Setup at Punch Press and Resin-Molding Lines. *Kojokanri*, 24(7): 53–58.

Minato, T. 1984. Japan's Subcontracting System Is Noticed in Overseas. *Nihon-Keizai Shinbun*, August 14.

Mitsuya, H., Tani, T. and Kagono, T. 1999. *Amoeba Management Can Change Your Company*, Diamond.

Mitsuya, H. 2000. Line-Company System of NEC Saitama, in: Tani, T. and Iwabuchi, Y., *Management Accounting of Competitive Excellence*, Chuoh Keizaisha, Chapter 14.

Monden, Y. 1978. Integrated System of Cost Management. *Sangyo Keiri*, December: 21–26.

Monden, Y. 1985. *Toyota System*, Kodansha.

———. 1987. *Just In Time: Toyota Production System Going Across the Ocean*. Japan Productivity Center.

———. 1989a. *Cases of JIT Production System of Automobile Industry*. Japan Management Association.

———. 1989b. *Foundation of Transfer Pricing and Profit Allocation*. Dobunkan.

———. 1991a. *Toyota Management System*. Japan Management Association.

———. 1991b. *Cost Management of Automobile Companies*. Dobunkan.

———. 1991c. *New Toyota System*. Kodansha.

———. 1991d. *Development of Transfer Price and Profit Allocation*. Dobunkan.

———. 1991e. Optimize the Small Lot and Frequent Deliveries for Mitigating the Congestion and Drivers' Shortage, *Nihon Keizai Shinbun* (*Nikkei Economic Journal*), August 7: 23.

Monden, Y. and Ohno, T. 1983. *New Development of Toyota Production System*. Japan Management Association.

Monden, Y. and Hiraoka, S. 1989. Financial Management of Automobile Company: Case Study of Toyota, *Keiei Kodo*, 4(1).

Monden, Y. 1994. *Target Costing and Kaizen Costing for Price Competitiveness*, Toyo-Keizai Shinposha.

Monden, Y. 2006. *Toyota Production System*, Diamond.

———. 2009a. *Management Change for Overcoming Depression*, Zeimukeiri Kyoukai.

———. 2009b. *Incentive Price (Profit-Allocation Price) for the Inter-Firm Cooperation*, Zeimukeiri Kyoukai.

Mori, K. 1978. The Negative and the Positive of Toyota Production System for My Standpoint. *Kojokanri*, 4(13): 145–148.

Mori, M. and Yui, N. 1982. Comparison of Production Systems of Japan–U.S. Auto Makers—Productivity Improvement Strategy and System of U.S. Automobile Industry. *Kojokanri*, 28(8): 17–65.

Morimatsu, T. 1988. Setup Improvements, in: Japan Management Association, *Seminar Text of Toyota Production System: Its Systematic Examination and Practical Application*. October 26–28.

Morita, T. 1981. Small Group Activities of Manufacturing Department: Toyota Honsha Plant That Emphasizes Quality Management, *Kojokanri*, 27(13).

Muramatsu, R. 1978. Basic Concepts and Structure of Toyota Production System. *Kojokanri*, 24(13): 162–165.

———. 1979b. *Foundation of Production Control, a New Edition*. Kunimoto Shobo.
Nagata, T. 1985. Let's Promote Medical Control of Facilities by Applying 5S, in: Kojokanri Editorial Dept. (ed.) *5S Technique, Kojokanri*. 31(11): Special issue, October.
Nakai, S. 1978. Toyota's Unique Vitality and Practicing Ability Developed Its Own System. *Kojokanri*, 24(13): 158–161.
Nakamori, K. 1986. Cost Management at the Design Department (1 and 2). *IE*, November: 65–70; December: 58–64.
Nakane, M. 1981. Mixed-Model Production System at the Body Assembling Line. *Kojokanri*, 27(7): 59–64.
Nakata, I. 1978. Complete Master of the Basic Concepts of Toyota System. *Kojokanri*, 24(13): 128–130.
Nakata, Y. and Monden. Y. 1985. Marketing Strategy of Automobile Companies—Theoretical Analysis of Toyota's Case. *Keieikoudo*, 4(11): 92–116.
Nihon Keizai Shinbun. 1981. Office Rationalization by Applying Kanban. November 7.
———. 1982a. Experimentation of Life-Time Employment System—Tentative Agreement between Ford and UAW. February 15.
———. 1982b. Teach Me the Kanban System—Request by U.S. Bendix Company to Jidosha Kiki Co., Ltd. March 2.
———. 1982c. Shock by the Alliance of Giant Automotive Companies, (1 and 2) March 9–10.
———. 1982d. Cooperative Movement in U.S. Industrial Relations Is for Real? June 7.
———. 1982e. (News Colloq.) Acceleration to the Effective Management of New Toyota. Mr. Toyoda, President of Toyota Motor Corporation. July 5.
———. 1982f. CAD/CAM System of Toyota—Body Development Process. August 5.
Nihon-keizai-shinbunsha, ed. 2002. *Panasonic: Bet for Revival*, Nihon-Keizai-Shinbun-sha.
Nikkan Kogyo Shinbun Sha. 1980a. Kojokanri editorial division, ed. *Honda's Small Group Activities*. Nikkan Shobo.
Nikkan Kogyo Shinbun Sha. 1980b. *Business Group for Support of Toyota*.
Nikko Research Center, ed. 1979. *Toyota in the 1980s—Its Growth Strategy Invested by Analysts*. Nihon Keizai Shinbun Sha.
Nikkei Business. 1996. Line-Company System of NEC (November 4, No. 864).
Nishibori, E. 1985. Morale Must Come Out from the Bottom of Heart, in: Kojokanri Editorial Dept. (ed.) *5S Technique, Kojokanri*, 31(11): 92–116.
Nissan Motor Company. 1981. *Annual Report (Financial Security Report)*. 1991 March. Ministry of Finance, July.
Noboru, Y. and Monden, Y. 1983. Total Cost Management in Japanese Auto Industry. *Kigyo Kaikei*. February, 35(2): 104–112.
———. 1988. Cost Management of an Automobile Company: Daihatsu Motor, in: Okamoto, K., Miyamoto, M., and Sakurai, M. (eds.) *High Tech Accounting*. Doyukan.
Noguchi, H. 1994. Toyota Motor Kyushu: Miyata Plant, *Kojokanri*, 40(11).
Noguchi, H. 1994. Functional Split Assembly-Line of Toyota Motomachi Plant That Realized Co-existence of Human and Machine, *Kojokanri*, 40(11).
Noguchi, H. 1995. Challenge of NEC Nagano That Achieved Production Innovation Based on Its Business Crisis, *Kojokanri*, 40(14).
Noguchi, H. 2005. New Systems Installed in the Mixed-Model Assembly Line at Toyota Tsutsumi Plant, *Kojokanri,* 51(1) 16–33.
Ochiai, T. 1991. Automobile Sequence Scheduling for the Assembly Line by Use of AI. Handout presented at the seminar of Japan Industrial Management Association, February 9.

Ohno, T. 1978. *Toyota Production System*, Diamond.
Ohno, T. 1982. *Field Management by Taiichi Ohno*, Japan Management Association.
Ohno, T. 1990. Multi-process Holding Is an Effective Method for Preventing Over-production. *Kojokanri*, 36(9).
Ohno, T. and Monden, Y., eds. 1983. *New Development of Toyota Production System*. Japan Management Association.
———. 1978a. Companies Gap Will Be Determined by the Productivity Gap When the Quantity Decreases. *IE*, March: 4–9.
———. 1978b. *Toyota Production System—Beyond Management of Large Scale Production*. Diamond.
Ohsai, T. 2004. Reformation of Economy by Each Functional Unit, Nihon-Keizai-Shinbun, May 17.
Ohshima, K. 1984. *Japan-U.S. Automobile Conflict—Investigation for the Strategy of Coexistence*. Nihon-Keizai-Shinbun-Sha.
Okada, Y. and Sasaki, T. 1986. Practice of Production Information Management at Matsuda. *JMA Production Management*, July.
Okamura, M. 1979. Toyota's Energy Conservation Prevailing throughout the Shop Floor. *IE*, September: 18–24.
Okano, M. and Yamamoto, K. 1986. New Technology of Assembly, Machining, and Inspection Systems, in: Watanabe, S. and Akiyama, Y. (eds.) *Production System and New Automation Technology*. Nikkan-Kogyo Shinbun-sha. 167–190.
Ozaki, R. and Morita, T. 1979. TQC and Toyota Production System Applied Together to the Production Control of Akashi Kikai Co., Ltd. *Kojokanri*, 25(8): 174–181.
Ryokaku, T. 1990. How the New Model Will Be Developed—Case Study of Celica. *Motor Fan*, Vol. 33, January.
Saito, S. 1978. *Secret of Toyota Kanban System*. Kou Shobo.
Satake, H. 1998. *Toyota Production System: Its Emergence, Development and Changes*, Toyokeizai Shinposha.
Sekine, K. 1978a. Steps toward Single-Setup: Procedures and Practices for Reducing the Setup Time in Half. *Kojokanri*, 24(7): 59–64.
———. 1978b. Toyota Kanban System, the Practical Manual. *Kojokanri*, 24(13): 2–52.
———. 1981. *Practical Toyota Kanban System—How to Make a Profit by Eliminating Waste*. Nikkan Shobo.
Senju, S., Kawase, T., Sakuma. A., Nakamura, Z. and Yata, H. 1987. *Motion Study: Determinate Edition*. JIS.
Shibata, F., Imayoshi, K., Eri, Y. and Ogata, S. 1993. Development of Quantitative Evaluation Method, TVAL, for Assembly Workload. *Toyota Technical Review*, 43(1), pp. 84–89.
Shibata, Y. and Hasegawa, N. 1981. Software Package for Support of Kanban, New Production Control System at Kyoho Seisaku Co., Ltd. *Kojokanri*, 27(4): 17–25.
Shimada, H. 1981. U.S. Industry Is Enthusiastic about Its Restoration Efforts for Improving the Quality of Labor. *Nihon Keizai Shinbun*, October 26.
———. 1984. Changing Labor Union of America: New Labor Contract in Automobile Industry. *Nihon-Keiai-Shinbun*, December 11.
Shimokawa, K., Fujimoto, T., Kuwashima, K. and Shimayama, Y. 2001. What I Learned from Mr. Taiichi Ohno: Oral Interview Document of Mr. Michikazu Tanaka, Former President of Daihatu Motor, in Shimokawa, K. and Fujimoto, T., Eds. 2001. *Origins and Evolution talked by Key Persons*, Chapter 3, 21–57.
Shimokawa, K. and Fujimoto, T. 2001. *Origin of Toyota System*, Bunshindo.

Shimokawa, K. 2009. *Is There Any Prospective Future in the Automobile Business*? Takarajima-sha.

Shingo, S., et al. 1978a. Single-Setup Will Change the Business Constitution. *Kojokanri*, 24(7): 1978a, 20–24.

Shingo, S. 1978b. Revolution of Setup Time Development to the Single-Setup. *Kojokanri*, 24(7): 20–24.

———. 1980. *Study of Toyota Production System from Industrial Engineering Viewpoint—Development to the Non-Stock Production*. Nikkan Kogyo Shinbun Sha.

Shinozawa, S. 1987. *Toyota's Chief-Engineer System of Automobile Development*. Kodansha.

Shioka, K. 1978. Toyota Production System and Work. *Kojokanri*, 24(13): 124–127.

Shishido, T. and Nikko Research Center, eds. 1980. *Japanese Companies in USA—Investigation in the Possibility of Japanese-Style Management*. Toyokeizai Shinpo Sha.

Shomura, O. 1981. Contemporary Auto Workers and Their Job Discontent—An Examination of the International Comparative Study by William H. Form. *Rokkodai Ronshu*, 28(2): 90–106.

Shukan-Diamond. 2003. Panasonic: Revolution 1000 Days, Vol. 91, No. 10, March 8, 28–47.

Shukan Toyokeizai. 1982. Toyota Kanban System Greets the New Stage, in: *The Toyota in 1990*. (Extra issue) July 1: 21–25.

Soukura, T. 1987. Setup-Time Reduction of Tandem-Press, in: *Setup-Time Improvement Manual. Kojokanri*, August, special issue, pp. 82–93.

Sugiyama, T. 1985. Floor Improvement Should Begin with 5S Application, in: Kojokanri Editorial Dep. (ed.), *5S Technique, Kojokanri*, special issue, 31(11): 38–67.

Suitsu, K. 1978. What We Learn from the Toyota Production System. *Kojokanri*, 24(13): 89–101.

———. 1979. Eight Articles of Basic Knowledge for Introducing the Toyota Production System. *Kojokanri*, 25(8): 202–220.

Suzuki, Y. 1980. Multi-functioned Worker and Job-Rotation Can Make Flexible Workshop. *IE*, May: 22–28.

Tagiri, I. 1981. "The Vitalities" Are Making Lively Activities around Mr. H.—A Case of Toyota's QC Circle. *Kojokanri*, 27(13): 139–144.

Takahashi, M., Kondo, J. and Tsuihiji, T. 1981. Fuji Heavy Industries, Ltd.—The Present Condition and Purpose of the Automation at Its Body Welding Plant. *Kojokanri*, 27(4): 37–45.

Takahashi, M. and Kondo, J. 1981. Microcomputer Aided Lamprey Type, Model Discriminating System for Supporting the Flexibility of Mixed-Model Production. *IE*, February: 28–30.

Takahashi, H. and Kubota, H. 1990. Assembly Line Control (ALC) System, in: Tokyo Management Association, *Seminar Text of Toyota Production System*, December 12: 1–16.

Takahashi, Y. 1989. Mixed Production of Tractor Plant. *Kojokanri*, 35(1).

Takano, I. 1978. *Complete Information of the Toyota Group*. Nippon Jitsugyo.

Takao, T. 1990. Toyota's Kaizen Budget: Original Feature of Japanese Style Budgeting. *Kigyokaikei*, 42(3).

Takeshita, S. and Mori, M. 1983. New Production Control System PYMAC of Yamaha, *Kojokanri*, 29(1).

Takeuchi, T. 1986. *Automobile Sales*. Nihon-Keizai-Shinbun-Sha.

Tanaka, H. 1978. *Employment Conventions in Japan and U.S*. Nihon Seisansei Honbu (Japan Productivity Center).

Terayama, S. 1989. Can Toyota Overcome a Large Company Sickness of Demeritmark System? *Nikkei-Business*, October 9.

Toda, M. 2006. *Toyota Information Systems Supporting the Toyota Way*, Nikkankogyou-Sinbun.

Tohno, H. 1978. Toyota System Lets Today's Production Follow Yesterday's Sales. *Kojokanri*, 24(13): 134–136.

Tokyo Shibaura Electric Co., Ltd., ed. 1977. *Promotion of Management by Objective*. Aoba Shuppan.

Tonouch Kogyo PCS Group. 1980. Computer-Aided Dispatching for the Mixed Body-Models at an Assembly Painting Maker. *Kojokanri*, 26(12): 68–72.

Toyota Motor Corporation. 1987. *Unlimited Creation: 50 Year History of Toyota*. Toyota Motor Corp.

———. 1987. *Unlimited Creation: 50 Year History of Toyota Materials*. Toyota Motor Corp.

———. 1991. *Annual Report (Financial Security Report): June 1991*. Ministry of Finance.

Toyota Motor Co., Ltd. 1964. Suggestion Committee Office, ed. *Manual of Suggestion System*.

———. 1966. QC Promoting Office. Promotion of Quality Control at Toyota Motor Co., Ltd. *Hinshitsukanri*, 17(1): 14–17.

———. 1973. *Toyota Production System for Cost Reduction* (unpublished), 1st and 2nd Editions (1975).

Urabe, K. 1984. *Japanese Style Management Can Evolve*. Chuo-Keizaisha.

Wada, R. 1979. Machining Automation in the Flexible Manufacturing System. *Kojokanri*, 25(8): 29–41.

Washida, A. 1978. A Commitment on the Toyota Manufacturing Methods. *Kojokanri*, 24(13): 131–134.

Yamada, Y. 1979. Points of Community and Difference between MRP and Toyota Production System. *Kojokanri*, 25(8): 96–110.

Yasuda, Y. 1989. *Suggestion Activities of Toyota*. Japan Management Association.

Yonezawa, N. 1983. Subcontractors under Their Reorganization in Industry. *Nihon-Keizai-Shinbun*. May 24.

Yoshikawa, A. and Minato, A. 1980. Total Optimization by Integrating the Design and Manufacturing Technologies. *IE*, April: 20–22.

Yoshimura, M., Miyamoto, T. and Hori, E. 1982. Optimal Sequencing Algorithm for the Assembly Line of the Medium Variety–Medium Quantity Models, in: Japan Operations Research Society (ed.) *Proceedings of Abstracts of 1982 Spring Research Conference*, pp. 147–148.

Yoshiya, R. 1979. Management Revolution by Means of MRP. *Diamond Harvard Business*. March–April:85–90.

Yoshiya, R. and Nakane, J. 1977. *MRP System—New Production Control in the Computer Age*. Nikkan Kogyo Shinbuh Sha.

———. 1978. Toyota Production System Viewed from the Standpoint of the MRP System Researchers. *Kojokanri*, 24(13): 102–108.

Yutani, M. 1990. Reduction of Set-Up Time, in: Tokyo Management Association (ed.) *Seminar Text of Toyota Production System* (unpublished).

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