SECOND EDITION

Lean Production for Competitive Advantage

A Comprehensive Guide to Lean Methodologies and Management Practices

John Nicholas

Foreword by Richard Schonberger

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By

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To Frank and Emily,

Elmer and Dolores

Contents

Foreword

In the outpouring of writings on lean production, the single work that tells it all and tells it well is this book by John Nicholas. It's fully stocked with excellent graphs, tables, photos, and mini-case examples, and with end-of-chapter questions for use as a classroom textbook.

This second edition retains and enhances the core material that made up the 16 chapters of the previous edition, plus the addition of three new chapters. Chapter 13 on the 3P Methodology joins eight prior chapters in Part II, key elements of lean production. The new Part IV, Lean Management System, tops off the book with Chapter 18 on daily lean management and Chapter 19 on strategy deployment in the cause of lean.

In Chapter 1, Race without a Finish Line, Nicholas presents lean as a force for *competitiveness*—a point of view often missing in lean lore. The chapter includes a review of lean's evolution, including its vibrant 1980s era under the just-in-time (JIT) banner.

Following that is Part I, Continuous Improvement, Waste Elimination, Customer Focused Quality, which sets the stage for subsequent chapters by making it clear that lean is not a one-time implementation—that it calls for never-ending improvement involving cutting wastes with quality in the eyes of customers.

Chapter 2 lays out the Fundamentals of Continuous Improvement and includes an expanded treatment of value stream mapping. I like what Nicholas has done with Chapter 3, Value Added and Waste Elimination, which, in addressing lean's commitments to time and quality, also looks at misunderstandings about the social impacts of lean. Chapter 4, devoted to Customer-Focused Quality, includes all the TQ basics with special attention to the essential involvement and ownership of quality by the work force.

As to lean itself, while many books and articles have been veering away from core methodologies, this book does not. The nine chapters in Part II, Elements of Lean Production, bore in on lean's essentials. Here are some highlights:

- *Chapter 5, small lots*: this chapter introduces the ideal batch size of 1—one-piece flow.
- *Chapter 7, equipment maintenance and improvement*: Some operations management textbooks don't even include this topic—but the lean community places special emphasis on its importance as pursued under total productive maintenance (TPM).
- *Chapter 9, focused factories and group technology*: While reviewing the classical forms of facility layout, this chapter properly answers the question, "On what to focus."
- *Chapter 10, work cells and cellular manufacturing*: In lean's early days (including the pre-lean JIT era), cellular manufacturing was often upheld as the key trigger for dramatic improvements in lead times. Unlike many other current publications on lean, this chapter convincingly retains that viewpoint.

- *Chapter 11, standard work*: Too often discussions and writings on standard work limit the topic to work instructions (standard, correct ways of doing tasks and jobs). This chapter is comprehensive and includes, for example, standard (maximum allowable) quantities of WIP.
- *Chapter 12, quality-at-the-source and mistake-proofing*: Among topics here is the all-important role of mistake-proofing, or in Japanese, pokayoking (my own terminology preference is fail-safe-ing, which avoids negative connotations).
- *Chapter 13, the new one on Production Preparation Process (3P)*: presents a formalized approach to what has been called collaborative design and development, simultaneous engineering, early involvement (IBM), and design build (Boeing).

Each of these chapters is presented thoroughly with plentiful examples, but what catches the eye are special insights.

Part III, Lean Production Planning, Control, and Supply Chains, contains four chapters that treat the traditional operations-management topic of production planning and control (PP&C)—but from a lean point of view. Besides the nuts and bolts of these topics, Nicholas includes broadened viewpoints. For example, Chapter 14, Uniform Flow and Mixed-Model Scheduling, advises that, for the sake of practicality and feasibility, leveling the schedule must be a “cooperative effort” carried out jointly by people from sales, marketing, engineering, production, and finance. Many excellent examples populate this chapter and keep it lively.

Chapter 15, Synchronizing and Balancing the Process, is a close companion of Chapter 14 and delves into line balancing under mixed-model production and adjusting to schedule changes. The chapter’s materials on synchronization—a high-interest issue in lean manufacturing—include how to match up different kinds of production. Scheduling around bottlenecks is part of the issue, and here Nicholas presents a set of principles for dealing with it.

Chapter 16, Planning and Control in Pull Production, takes a higher-level system-wide approach to the subject: centralized versus decentralized; monthly and daily planning; links with suppliers under kanban vs. MRP (material requirements planning); capacity plans and bills of materials; stocked shelves vs. point-of-use; and the knotty matter of operating a pull system alongside with MRP.

Chapter 17, Lean Production in the Supply Chain, is an essential component of the book. Besides core issues (e.g., supplier partnership, sourcing, supplier certification, orders and contracts), the chapter includes discussion of the Aisin Seiki crisis in which a key Japanese automotive supplier was nearly put out of business by a fire at the plant.

Part IV presents new materials on the Lean Management System. Chapter 18, Daily Management, contrasts traditional management behaviors to the very different and much more effective behaviors under lean. It addresses the challenges of maintaining process stability and improvement, cultural and leadership aspects of management, and methods for tracking daily progress and sustaining improvements.

Chapter 19, Strategy Deployment, offers a systematic approach to linking components of the lean agenda to organizational strategies. The concept calls for blending high-level organizational goals, policies, and strategies such that the many elements of lean support goals.

To sum up, *Lean Production for Competitive Advantage* is an adroitly written book that fills yawning gaps in the lean discipline. Lean practitioners, consultants, teachers, and students will not find another book so comprehensive, readable, and on target.

Richard J. Schonberger

Richard J. Schonberger, formerly a university professor (University of Nebraska) and affiliate professor (University of Washington), is an independent researcher/author/speaker based in Bellevue, WA. He is author of some 180 published lean/TQ-oriented articles and seven books, including *Japanese Manufacturing Techniques* (1982); *World Class Manufacturing* (1986); *World Class Manufacturing Casebook* (1987); *Building a Chain of Customers* (1990); and *Best Practices in Lean Six Sigma Process Improvement* (2008).

Preface

Around 1989, after reading Richard Schonberger's *World-Class Manufacturing: The Lessons of Simplicity Applied* (The Free Press, 1986), Robert Hall's *Zero Inventories* (Dow Jones-Irwin, 1983), and Kiyoshi Suzaki's *The New Manufacturing Challenge* (The Free Press, 1987), and talking to former students who had become practitioners and consultants in manufacturing about emerging developments, I decided to offer a course focused on just in time—JIT. At the time there were no textbooks on JIT, just some trade books that covered the topic, so I adopted these for the course. Trade books tend to skip over the basics and do not include homework questions and problems, and for this I had to write my own material. Over the years I accumulated more and more of my own writings, and about the time this material covered half the topics in the course I decided to write a textbook and put everything in one place.

The first version of this book was published in 1998. Management concepts seem to come and go with the seasons, but the important ones remain alive even though the terminology changes. JIT is still alive and thriving, although nowadays it is called lean production and the term JIT is reserved for narrower, logistical applications of lean. In this book the terms lean production and JIT mean roughly the same thing and are used interchangeably.

In and around my city, Chicago, there are many businesses and ample opportunities to see both the best and the worst in manufacturing management. I have been excited and encouraged in visiting plants and hospitals that have embraced the concepts and methods of lean production, including continuous improvement and emphasis on waste elimination and customer-focused quality. Managers and workers in these businesses enthusiastically talk about what they are doing. Students in my class often express the same level of enthusiasm, discovering that, yes, lean production is cool. Others with manufacturing experience express frustration because of problems in their workplace and management's ignorance about lean production concepts and unwillingness to change. I can relate to that, having seen plants that seem like throwbacks to 70 years ago and talked to workers with demeaning jobs and managers out of touch with the workforce and customers. These businesses represent the antithesis of lean production.

The concepts and principles described in this book have revolutionized manufacturing practice and business conduct in the same way that Henry Ford's system of mass manufacturing did 100 years ago. They have done so because, simply, they work—they are *effective.* Because they are effective, the *only* companies that can compete with companies that have embraced lean principles are companies that have also embraced them and make products that customers want.

Beyond effectiveness, many find lean production appealing because of the somewhat high level of responsibility and dignity it attaches to the jobs of workers on the shop floor. I was raised in a working-class family and always felt that my parents' abilities exceeded what they could exercise in the workplace. My dad was one of the smartest and all-around most capable men I have ever known and I always thought he could build or fix anything requiring mechanical, electrical, or carpentry skills. When I think about teams of workers in lean organizations, I envision people like my parents as representative of many millions of workers and of the opportunities and fulfillment that lean-style production can offer them. That is not to say that lean organizations are a kind of utopia but that, on balance, workers in lean factories have more opportunity to find meaning in their jobs and gain more respect from management than workers in other factories.

The emphasis in this book is on lean production concepts and tools. As such it focuses on methods and procedures, although it must be said that in any organization the success of methods and procedures depends on their acceptance and implementation. Lean production is more than methods and procedures; it is a management philosophy that emphasizes relationship-building and trust, and responsibility conferred to frontline workers and suppliers. Thus, successful adoption of lean production requires adopting not only particular methods and procedures but also an organizational culture that supports those methods and procedures. In lean companies decision-making responsibility is much more decentralized and its locus is decidedly much lower in the organizational hierarchy than in non-lean companies. This shift in responsibility follows a make-over in assumptions at all levels of the organization, from shop floor supervisors to the CEO, about the roles and responsibilities of frontline workers and suppliers and their involvement in day to day decision-making. If an organization is not able to successfully adopt the methods and concepts of lean production it is likely because it is not able to adopt a culture that fully involves its employees and suppliers.

There is much to learn about lean production. Beyond the basics described in this book you can learn about new developments and applications in all industries from the pages of trade journals such as *Target*, the journal of the Association for Manufacturing Excellence.

Einstein said, "I know why there are so many people who love chopping wood. In this activity one immediately sees the results." Lean production practices are that way. They represent pragmatic approaches to chopping away at waste and problems in organizations. In many organizations you can see results on the shop floor or in the office not too long after putting aspects of lean production into practice. Improvements on the balance sheet of course happen too, but will appear a little later.

Audience and Use of this Book

Lean Production for Competitive Advantage was written for the following audiences:

1. Students in bachelor of business and MBA programs interested in operations management.
2. Students in industrial and manufacturing engineering.
3. Practicing managers and engineers in operations seeking to better understand lean production.
4. Anyone—students in any major or managers in any field—interested in improving processes.

For students, the book is intended as a second-level course. Anyone having taken an introductory course in operations management should have no difficulty with the material.

The book is divided into an introductory chapter and four main parts. Chapter 1 and Part I provide foundation concepts for everything that follows. Part II covers the core methods of lean production. Part III covers integrated planning and control in lean production and the supply chain. Part IV covers management practices. It might be difficult to cover the entire book in a typical one-term college course, and the instructor must decide on which topics to focus. I believe that everything in Parts I and II and Chapter 18 should be covered in some depth. Depending on students' prior exposure to planning and control, portions of Part III might be skimmed or omitted, although I suggest that no chapter be completely skipped. Most of the topics in this book are interrelated and to gain a full understanding of lean production it is necessary to know about all of them.

Second Edition

In this second edition I have tried to address the significant matter of management's role in lean production. Early observers of Japanese methods focused on the shop floor to see amazing things unlike anything practiced elsewhere in the world. And the thinking was, if the "methods" could be adopted by companies elsewhere, those companies would experience the success of the Japanese. Over the following decades numerous companies attempted to implement these methods. Some succeeded; most failed. What the early observers hadn't taken into account—in many cases weren't even aware of—were dramatic differences in the way companies using those new methods were managed, both daily and strategically. Fact is those methods—practices now called lean production—unless directed and supported by management are unlikely to succeed or be sustained in the long run. In this edition I have addressed the "management side" of lean production in two new chapters, one devoted to daily management, the other to strategic management.

This second edition includes many other additions. In lean production continuous improvement happens mostly through sustained incremental improvement, but also through occasional radical or breakthrough improvement. I have added a new chapter to address breakthrough improvement and discuss an approach to achieving it called Production Preparation Process.

Every chapter has been revised and expanded to better tell the story of lean production—its history, applications, practices, and methods. Over the 8 years since the last edition was published I have continued to learn about lean production from managers who practice lean, scholars who study it, and teachers and students who adopt and use my books. In this edition I have incorporated these learnings to the best of my ability.

Acknowledgements

In writing this book I have had the good fortune of being assisted by many bright and capable people. Drs. James Zydiak and Enrique Venta read parts of earlier versions of the book and provided useful suggestions. Sam Mulroe, Paul Garanzini, Sugandhi Thusoo, Sosamma Mammen, Marco Menaguale, Marlene Abeysinghe, Leslie Bailyn, Diane Petrozzo, and Omar Saner, my students and graduate assistants, provided research and editorial help. In case you find the going difficult with some of what you read, you can only imagine what it was like for them many drafts earlier. On the other hand, if perchance you think the material reads with exceptional clarity, it is no doubt due partly to their efforts.

Thanks also to Avi Soni and Al Brouilette, two enthusiastic managers who I believe represent the best examples of people who have embraced the true meaning of lean production. I learned a great deal about learn production from frequent visits to their plants and numerous discussions with them and their co-workers. Avi championed the successful makeover to lean production in his plant and is to me the quintessential transformational leader. Two other managers, transformational leaders really, also stand out: Greg Horner and the late Deb Kuhl. I owe them special gratitude for opening their workplace to me and sharing their substantial knowledge. Deb showed that what she had learned and practiced at Toyota could be applied as readily to healthcare. More than a manager she was a sensei. Greg took over where Deb left off and he too has become a sensei. Thanks also to Richard Schonberger for his comments and suggestions on this edition and for introducing me and so many others to lean production—even before people called it that.

I also want to acknowledge the reviewers of earlier editions of this book whose comments and suggestions improved the end product: Luc Chalmet, Mary Jo Maffei, Behnam Malakooti, Unny Menon, George Schneller, Kenneth Ramsing, Joe Biggs, Karen Donohue, Vaidyanathan Jayaraman, Pitu Mirchandani, Byron Finch, and George Petrakis.

Thanks also to the folks at CRC/Productivity Press, especially to the late Ray O'Connell for encouraging me to sign on.

Finally there is my wife Sharry who has my deepest appreciation for patiently having assumed responsibility for managing virtually every aspect of our home life so I could work undistracted.

The assistance of her and so many people made writing this book not only doable but enjoyable. Most of them share with me an excitement about lean production. My one wish is that you, after having read this book, come away with that same sense of excitement.

I apologize in advance for typos and mistakes in the book. I had final say over everything, so I accept responsibility for these as well as any other source of anguish this book might cause. For your sake I hope there aren't too many, but if you see any please let me know.

About the Author

Dr. John Nicholas is professor of operations management at Loyola University Chicago where he teaches in the areas of production and operations management, healthcare management, project management, and global operations management. He first introduced a course on lean production at Loyola in 1990. As a management consultant he has conducted productivity improvement projects and training programs in process improvement, quality circles, project management, and teamwork, and has actively participated in many kaizen and hoshin events in manufacturing and healthcare organizations.

He is the author of numerous academic and technical trade publications and four books, including *The Portal to Lean Production: Principles and Practices for Doing More with Less* (coauthored with Avi Soni, 2006, published by Auerbach) and *Project Management for Engineering, Business, and Technology: Principles and Practices* (coauthored with Herman Steyn, 2017, published by Routledge).

Prior to Loyola, Dr. Nicholas held the positions of test engineer and team lead for Lockheed/Martin Corporation, senior business analyst at Bank of America, and research associate at Argonne National Laboratory. He has a BS in aerospace engineering and an MBA in operations research and management, both from the University of Illinois, and a PhD in industrial engineering and applied behavioral science from Northwestern University.

Chapter 1

Race without a Finish Line

> What we really cannot do is deal with actual, wet water running through a pipe. That is the central problem we ought to solve some day.
>
> **Richard Feynman**

Most people have heard of Xerox, the company that invented the paper copier and for a time one of America's best-known corporate names and employer of 100,000 people.[1] Like so many successful companies, however, it has had its share of struggles—both in maintaining market share and even staying in business. In the early 1980s, Xerox executives realized that if something radical was not done, Xerox probably would not survive to the end of the decade. The problem: Japanese companies were selling copiers for less than it cost Xerox to make them, and they had targeted Xerox to capture its market and wipe it out altogether. For Xerox, the situation was dire: Its market share was less than 15%, down precipitously from the more than 90% share it had enjoyed a decade earlier. But the competition alone was not the cause: There was no quality control to speak of, overhead and inventory costs were excessive, and there were too many managers. Further, Xerox had lost touch with its customers and was not giving them the products or service they wanted. At one time, Xerox had no competitors. Now, it had many, and customers were flocking to them.

Xerox managers and a core group of unconventional corporate thinkers mapped out a strategy to remake the company. The strategy succeeded. Xerox doubled its production output, reduced its costs by nearly 50%, reduced its product development cycle time by nearly a year, and dramatically improved the performance of its copiers. By 1990, Xerox had become the producer of the highest quality office products in the world and had gained back market share from the Japanese. By 2004, it still retained a dominant share of the high-end color copier market. Xerox accomplished this not with government subsidies, trade barriers, or import quotas but rather by adopting new management approaches that included the tenets of **lean production** and **total quality management**.

Successful recovery is, of course, not the fate of every company that has faced tough competition from overseas. It took Xerox seven years to reinvent itself, but many companies cannot afford such time. Every company is vulnerable, and the aeronautics industry is a good case in point. Up through the 1960s, the United States had been the world leader in the commercial aircraft business, holding nearly 100% of the free-world share. But in 1969, a consortium of companies from France, Germany, the United Kingdom, and Spain began to aggressively pursue that market, and the U.S. share since has steadily declined. The European share is now roughly 50%. This is not an insignificant fact given that the aeronautics industry is the single biggest manufacturing contributor to the U.S. balance of trade.

As the number of skilled contenders in a given market increases, so does the intensity of the competition. Initially, in new and growing markets, many players can survive by absorbing a portion of the growth in market size. In the global economy, the market size is large, but so is the number of players. Eventually, as market size levels out or as players differentiate themselves by ability to compete, the more skilled players drive out the less skilled players.

Competitive Advantage: Better, Cheaper, Faster, More Agile

In no small part, what differentiates competitiveness in industrial companies is the way that each designs and builds products. Paying attention to customers and knowing what they want is a fundamental beginning. However, given that competing companies all pay attention to what customers want, the key to competitiveness then becomes production capability. The differentiator between winners and losers is that winners are better able to consistently provide products and services that are competitive with regard to quality (better), price (cheaper), time (faster), and response to change (agile).

To this end, companies adopt different manufacturing philosophies, strategies, and methods. These differences are part of what distinguishes lean companies from traditional companies.[2]

- *Making things better*: Traditional manufacturers strive for quality by relying heavily on computer-aided design (CAD)/computer-aided manufacturing (CAM) to enhance product design and manufacturability. In contrast, lean firms rely more on group technology and cellular manufacturing, good condition and proper placement of equipment, smaller manufacturing units, and improvement-focused employee teams. Both kinds of manufacturers rely on statistical process control, defect-reduction programs, and vendor quality programs.
- *Making things cheaper*: Traditional manufacturers tend to rely on job enlargement programs, automation, and robotics to reduce direct labor content. In contrast, lean firms seek to achieve low cost by redesigning and simplifying products and processes, standardizing products, and reducing lead times and cycle times.
- *Making things faster*: Traditional producers rely on robotics and flexible manufacturing systems, location of facilities, and improved labor–management relations. Lean companies emphasize continuous reduction of lead times and setup times, equipment maintenance, and broadening of workers' jobs.
- *Being more agile*: The ability to introduce new products and to respond quickly to changing customer demands is an area where lean companies enjoy a wide lead over traditional firms.[3] Traditional firms seek agility through technology, process flow improvements, quality management, and cross-functional communication improvements. Lean firms consider agility an integral part of quality and delivery capability, and a by-product of programs to improve these areas. Thus, programs aimed at producing things better and faster are also aimed at achieving manufacturing agility.

Lean producers also take a somewhat different approach to product development. In traditional firms, product ideas tend to move sequentially through functional areas (from marketing, to engineering, to production, etc.), whereas in leans firms they percolate in dedicated product development teams. The latter allows integration of ideas during the early design stages, takes less time, and results in a better product at lower cost.

Lean Production and Total Quality Management

Another difference in the competitive strategies of traditional manufacturers versus lean manufacturers is that the former seek improvement at discrete times through capital-intensive means, such as automation and new technology, whereas the latter seek improvement through small but continuous refinements in processes and procedures, and investment in human capital. Lean production and the tandem management philosophy of total quality management (TQM) emphasize *continuous* attention to product and process improvements, and involvement of frontline workers in those improvement efforts.[4] Briefly:

- Lean production is management that focuses the organization on *continuously identifying* and *removing sources of waste* so that processes are continuously improved. Lean production is also called **just-in-time** or **JIT**.
- TQM is management that focuses the organization on *knowing what customers need and want* and on building capabilities to fulfill those needs and wants.

This book is primarily about lean production, but it is also about TQM because the two philosophies are mutually dependent and, in some respects, the same. To paraphrase Schonberger,

Lean is a quality improvement tool because it cuts time delays between process stages so that the trail of causal evidence to quality problems does not get cluttered and cold. But TQM tools are needed as well or the rate of quality improvement will not be fast enough. To oversimplify, lean without TQM will be a quick response to quality problems, but to a dwindling number of customers. TQM without lean will meet correctly identified customer needs, but using methods that are costly and wasteful.[5]

That the philosophies and practices of lean production and TQM overlap is not surprising since both originated in Japan in the 1950s.[6] In fact, the distinction between what is lean and what is TQM is an artifact of the way Westerners chose to adopt Japanese practices. Such a distinction never existed in Japan.

Lean Production and the Production Pipeline

Think of a company as a pipeline with raw materials entering at one end and products exiting at the other.[7] The goal is to minimize throughput time, that is, to move materials (or ideas, or orders) through the pipeline as fast as possible. Shorter throughput time is better because, assuming price and quality remain constant, the company can respond more quickly to changes in customer needs. The customer gets the product sooner; the company gets the payment sooner.

But the production pipeline is seldom uniform and without obstacles. What flows out of the pipeline is limited by the biggest obstruction. Portions of the pipeline that are obstructed are in reality equivalent to the stages of the production process where stoppages or slowdowns occur. Obstructions to uniform flow and rapid throughput are commonplace, particularly in plants that produce a variety of products with different, fluctuating demands.

To speed up the flow through the pipeline, the obstructions must be identified and eliminated. As each obstruction is eliminated, the flow speeds up, but only by as much as allowed by obstructions elsewhere in the pipeline. Identifying the obstructions, understanding them, and finding ways to eliminate them is the thrust of lean production.

The pipeline analogy gives the impression that barriers to production, once identified, can be removed once and for all. In reality, that is impossible. First, there are often a large number of phases, stages, or steps, and it is difficult to identify the precise location of every obstruction. Also, the sources of obstructions keep changing—machines break down, parts run short, and so forth. As some obstructions are removed, new ones appear. Further, the pipeline itself and the things that flow through it are always changing. Customer orders change, so the flow rate must be adjusted to accommodate the right kind and quantity of materials. In the analogy, the pipeline diameter might have to be widened or narrowed. A pipe that is wider than necessary is wasteful, and so is a flow rate that exceeds demand. In addition, the products are changing too, so the process must be adapted (the pipeline itself must be modified or replaced), and that introduces a whole new set of obstructions. In short, work on the pipeline is continuous.

Lean production is a way of continuously tinkering with the pipeline so the material coming out of it is the best possible. Lean production continuously seeks ways to make the pipeline more adaptable to whatever materials or flow rates are desired, to match the material flow as closely as possible to customer demand, and to make the material coming out ever more satisfying to the customer.

The Lean Difference

Most organizations seek to identify and eliminate obstructions in the pipeline, but two features distinguish lean organizations. First, lean organizations greatly increase the number of people involved in the effort. Whereas most companies assign professional staff to diagnose and solve problems, in lean organizations everybody does it. People at all levels are trained in analysis and problem-solving techniques and given some level of responsibility to generate improvement solutions and implement them. The general level of responsibility of workers everywhere in the company to make and carry out decisions is much higher in lean companies than elsewhere.

A second difference is in the practices employed to identify and prioritize problems. In lean companies, this starts with setting difficult goals and then looking for obstructions to meeting those goals. For example, one objective of lean production is to eliminate inventory. Most companies carry inventory so that when problems arise—parts shortages, equipment breakdowns, defective parts, and so on, production continues uninterrupted. As inventory is reduced, however, operations are interrupted and it becomes *necessary* to identify the problems causing the interruptions. As it is further reduced, additional problems arise and these must be dealt with too. With each new problem, solutions are identified, and these are incorporated into the production system through new procedures and standards of work so they won't occur again. Reducing inventory leads to improvement.

Important to note, however, is that inventory reduction per se is *not* the ultimate objective in lean production but a means to identifying problems and waste. Any inventory reduction by itself yields a one-time benefit of freed-up capital, but unless problems in the production system—previously hidden or ameliorated by the inventory—are resolved for good, the process will not be improved and might be worsened. This is why companies that try to reduce inventories as a goal rather than as a tool to identify and remove problems usually fail.

Toyota, where lean production originated, has several such long-term goals (referred to as the "True North" vision):

- Zero defects
- 100% value-added
- One-piece (no inventory) production to meet demand
- Stabled processes, uniform (level) demand and production
- Security for people

That the goals might never be completely achieved is of less importance; what is important is the never-ending process of *trying* to achieve them and the continuous improvement that results.

The following sections give a brief history of the origins and evolution of manufacturing and lean production.

Evolution of Manufacturing

The Machine that Changed the World[8]

One of the most informative and interesting introductions to lean production is the book *The Machine That Changed the World.* The machine in the title is the automobile, and the book is about the auto industry. The automobile is truly the machine that changed the world because twice in the twentieth century the auto industry changed the way products everywhere were made. The first change came after World War I when Henry Ford and Alfred Sloan advanced manufacturing from *craft production* to *mass production*. Whereas for centuries Europe had led the manufacturing world with the former, America swiftly became the dominant global economy with the latter. The second change came after World War II, when Eiji Toyoda and Taiichi Ohno at Toyota Motor Company pioneered lean production. The economic rise of Toyota and of other companies and industries in Japan and elsewhere that adopted lean production was a consequence.

Craftsmanship Yields to Industrialization

Prior to the beginning of the Industrial Revolution, usually associated with James Watt's development of the steam engine in 1769, the emphasis in production was on skilled craftsmanship. Craft guilds promoted workmanship and manual skills using hand tools, and almost everything was produced by craftsmen and their apprentices. Craftsmen performed tasks that demanded high-level workmanship, and apprentices learned from them while performing preliminary tasks. Not until 1776 when Adam Smith wrote *The Wealth of Nations* did the notion of increasing productivity by dividing tasks among more than one specialist gain prominence.

Around 1780, Eli Whitney in the United States and Nicolas LeBlance in France independently conceived the idea of the *interchangeable part*, whereby parts would be made in batches such that any one part would meet design tolerances and fit into an assembled product. With the implementation of the interchangeable part in production of rifles, clocks, wagons, and other products, a slow transformation began that would replace hand labor and craftsmanship with mechanization and division of labor.

Around the early 1900s, Frederick Taylor introduced the idea of improving operations by studying and simplifying them. Always looking for the **one best way** to do something, he developed techniques for systemizing and improving economies of work motion, as well as a complete management philosophy that included time analysis, wage incentives, separate responsibilities for managers (planning) and workers (doing), an accounting system, and principles for running a business on a scientific basis. Taylor inspired legions of contemporaries, including Frank and Lillian Gilbreth who extended Taylor's time study to include the detailed analysis of motion. Their ideas about work measurement, analysis, and management contributed to the theory of *scientific management*.

One consequence of this theory was to take most of the skills and thinking away from factory workers (de-skill jobs) and give them to legions of managers and specialists. Factory work was divided into narrow, repetitive tasks, and workers were stripped of all control. As this happened, work on the shop floor began to lose its appeal. It is significant to note that the Japanese never wholly embraced Taylor's system of specialization and its rigid rules separating responsibilities between workers and managers. In Japan, workers in factories continued to develop broad-based skills that would allow them to rotate freely among a variety of tasks. This continuing emphasis on skill development, as well as on delegation of responsibility and the expectation that factory workers would both plan and do work tasks, resulted in a level of worker commitment virtually unseen in Western factories.[9] The consequence of this would not be recognized until half a century later.

Craft Production of Automobiles

Cars were a luxury only the rich could afford. They were initially handmade by skilled craftsmen who were knowledgeable in design principles, materials, and machine operation. Many of these craftsmen went on to form their own machine shops and become contractors to auto-assembly companies.

Few cars were actually identical, since every shop produced parts according to its own gauging system. Specifications on parts were only approximations, and car assemblers would have to file down and hammer parts so they would fit together. Lack of product uniformity did not matter much since most cars were built for individual buyers. Minor design features, location of controls, and some materials were changed to meet buyer preferences.

In the early 1900s there were hundreds of companies in Western Europe and North America producing autos, although each made less than a 1000 a year and rarely made more than 50 from a single design. Because the small shops that supplied parts lacked resources, there was very little product or process innovation. As a result, cars were poor in terms of consistency, reliability, and drivability.

Ford's Mass Production System

As a young machine-shop apprentice, Henry Ford envisioned producing an inexpensive auto. In 1903, at the age of 40, he started the Ford Motor Company and began producing the Model A. Each car was produced on a fixed assembly stand, and a single worker assembled a majority or all of it. The worker got his own parts; if a part didn't fit, he filed and pounded it until it did. Ford saw the limitations of parts being inconsistent and introduced Whitney's idea of standardized, interchangeable parts.[10] Using interchangeable parts, any worker could be trained to assemble a car, and since all cars would be virtually identical, anyone could drive and repair one. Thus, Ford began to insist that all parts be produced using the same gauging system and that the parts be delivered to the assembly stands so the assemblers could work in one place uninterrupted all day.

By 1908, when the Model T was introduced, Ford had modified the process so that each assembler moved from car to car and performed only one task on each car. Although such specialization would presumably increase efficiency, the problem was that faster workers would catch up with and have to wait behind slower workers. As a solution, Ford introduced in 1913 another major innovation: a *moving assembly line.* He got the idea at a slaughterhouse watching carcasses on hooks move from workstation to workstation by an overhead bicycle-chain mechanism. The "line," which brought the cars past stationary workers, eliminated time wasted by workers walking and forced slower workers to keep up with the pace of the line. Whereas before it had taken 13 hours to make a car, it now took just one and a half. Ford's competitors realized the productivity advantage of the combination of interchangeable parts and the moving production line—what became known as Ford's *mass production system*—and eventually companies around the world adopted the system.

While perfecting the interchangeable part, Ford was also perfecting the "interchangeable worker" by obsessively applying the teachings of Frederick Taylor. Whereas the Ford worker of 1908 gathered parts and tools, repaired tools, fitted parts together, assembled an entire car, and checked everything, the Ford worker of 1915 stood at a moving line and did one simple task. Workers caught slacking off or performing inadequately were quickly replaced. The atmosphere did not inspire workers to point out problems or offer suggestions, so problem-solving was assigned to foremen, engineers, and battalions of functionally specialized workers. With time, these specialties all became narrowly subspecialized, eventually so much so that staff in one subspecialty would have trouble communicating with staff in other subspecialties.

By 1931, Ford had brought every function necessary to car production in house, the concept of vertical integration taken to the extreme. Not only did the company make all of its own parts, it also controlled the procurement and processing of basic materials such as steel, glass, and rubber. Ford did this partly because he could produce parts to closer tolerances and tighter schedules than his suppliers and partly because he distrusted his suppliers.

To make parts inexpensively, machines were needed that could make them in high volume and with little downtime for changeovers. Ford eliminated downtime by using machines dedicated to doing one task at a time. Because it is difficult and costly to modify products using dedicated machines, new products were avoided. But the rigidity of the system did not matter because, from 1908 through 1927, Ford produced only the Model T. Throughout this period, Ford's goal was to keep increasing Model T volume so that the cost would continuously decrease. Ford believed that because high volume results in lower unit costs and allows prices to be reduced, mass production precedes mass consumption. By 1926, Ford was the world's leading manufacturer, producing half of all cars. Not until the 1950s did a car outsell the Model T in numbers; that car was the Volkswagen Beetle.

But all was not well. Quality control of the Model T was lax. Finished cars were rarely inspected, but they were durable and could be repaired by the average user. Little about the car had been changed in ten years and price had become its sole selling point. Customers began looking elsewhere for more innovative and exciting products. In 1926, sales began to slip.

Emergence of Modern Mass Production

General Motors (GM) was created when William Durant acquired several car companies. Early on the enterprise fared poorly because the companies had separate management and overlapping products. Alfred Sloan, upon becoming GM's president in 1920, instituted a new management philosophy that would complement Henry Ford's mass production system. He reorganized GM into five car divisions covering the market continuum, low end to high end, and into parts-specialty divisions.[11] He also divided management into functional areas and originated the new functions of financial management and marketing. By 1924, GM had become a serious challenger to Ford.

The production system at Ford put workers under increasing pressure, sometimes pushing them to the extremes of endurance. By 1913, when most jobs in the system had become menial and relentless, turnover reached 380%. To stem the flow and attract better workers, in 1914 Ford doubled the daily wage to the then-phenomenal amount of $5. The pay hike worked, and most workers stayed and came to view Ford as a place of permanent employment, despite unbearable work conditions. But Ford treated the workers as expendable, and in a market turndown would lay them off in a moment. Not only at Ford, but also at GM and other automakers, workers were considered little more than pieces to be manipulated as needed. As a result, the workers organized and formed a union, the United Auto Workers (UAW), which by the late 1930s had gained enough strength to force the automakers into an agreement whereby seniority, not job competency, would determine which laborers were laid off and who got certain job assignments. Management in all major industries, not just automobiles, fought labor unions long and hard, and by the time the unions finally gained power, hate and distrust had swelled. Labor and management had become adversaries and would remain so for decades (in some cases, they still are).

The system of mass production today is largely a result of the combined influence of Ford, Sloan, and organized labor. Starting in the 1930s, the system served as the means for increasing economic gains for both employers and workers in the United States. By 1955, sales of the Big Three U.S. automakers accounted for 95% of the more than 7 million autos sold in the United States that year. That was their peak year. Afterward, their share began to dwindle as the share from imports steadily grew.

Mass Production Around the World

Economic chaos, nationalism, World War II, and strong attachment to craft production had prevented European automakers from widely adopting mass production until the 1950s. When the Europeans did adopt mass production techniques, low wage costs and innovative features gave them a burst of success in world markets. That success dampened, however, during the 1970s, by which time wages had increased and work hours had decreased to the point where European cars were no longer price competitive. In 1973, the oil embargo hit; gasoline prices worldwide soared. Even though the typical U.S. car was a gas-guzzler and the average European car was smaller and more fuel efficient, the latter was also higher priced and posed no real competitive challenge to U.S. automotive dominance. Elsewhere, however, the real challenge was forming, though it was totally unperceived. It was in Japan.

Toyoda and Ohno

The Toyoda[12] family had been in the textile business since the 1800s. In 1935, it began producing cars, but the cars were crude and poorly made. In 1950, young Eiji Toyoda visited Ford's River Rouge plant to learn the methods of mass production. The plant seemed to him a miracle of modern manufacturing: Almost everything that went into an automobile—parts, components, and assemblies—was produced in this one monstrous plant. In one end, went raw materials like iron ore; out the other end, rolled cars, 7000 a day. Toyoda wanted to learn how Ford did that. (At the time, Toyota over its entire history had produced fewer than 2700 cars.)

After 3 months of studying the plant, however, Toyoda concluded that Ford's mass production system was unworkable in Japan, which was still struggling to recover from the ravages of war. Since Japan had few auto manufacturers at the time and a small auto market, Toyoda wanted to make a variety of cars in just one plant. In the United States, only one type of car could be produced in a plant. Because of strong Japanese company unions, he knew he could not readily hire and fire workers as was common in U.S. firms. Also, because of the short supply of capital, he would not be able to invest heavily in modern equipment and technology.

Returning home he called on Taiichi Ohno, Toyota's chief production engineer, to help develop a workable system. Ohno too visited Detroit and concluded he would have to design a system that would be much less costly and wasteful, but more efficient and flexible than Ford's traditional mass production system. The system he and others at Toyota developed, called the **Toyota production system (TPS)**, is the prototype for lean production and JIT manufacturing. Though developed for automobile production, the principles of the system have since been applied in all kinds of industries.

Toyota Production System—Prototype for Lean Production

This section gives an overview of the features of TPS and what distinguished it from traditional mass production. Many of these features, which are covered in more detail throughout the book, were evolved as ways to help Toyota continuously improve in terms of reducing wastes and better meeting customer demand.

Reduced Setup Times

The American practice was to use hundreds of stamping presses, each for making only one or a few kinds of parts for a car. These huge presses sometimes required months to set up. Since Toyota's budget limited procurement to only a few stamping presses, each press would of necessity have to stamp out a variety of parts. To make that practical, the setup times for switching over from stamping one kind of part to another would have to be drastically reduced.

By carefully analyzing existing procedures, Toyota devised methods that slashed setup times from months to just hours. By organizing procedures, using carts, and training workers to do their own setups, the company was eventually able to get the setup time down to an amazing 3 minutes.[13] The procedures developed at Toyota can be applied to any setup in almost any workplace.

All setup practices are wasteful because they tie up labor and equipment, and add no value to the product. Despite this, the tradition, before Ohno, was to take any setup practice as a given; if the setup takes a long time, so be it. In fact (so goes traditional thinking), if a setup takes a long time, it would be necessary to produce things in large batches to justify that setup time. Since setup times were usually long, large-batch production became the norm in manufacturing.

Small Batch Production and One-Piece Flow

The traditional practice of producing things in large batches (large lot size) was justified not only by a high setup cost but also by the high capital cost of high-speed, dedicated machinery. Dedicated machinery is very efficient, but it is also expensive, and somehow managers feel the expense can be justified if they keep the machinery running to produce things in massive quantities, regardless of demand.

But producing things in large batches results in larger inventories because it takes longer to use up each batch, and that, in turn, results in higher holding costs. Plant-wide large-batch production also extends lead times because it ties up machines longer and reduces scheduling flexibility. The effect on lead times is negligible when demand is constant but it increases as the demand variability increases.

Large size batches also tend to have higher defect costs. Production problems and product defects often happen as a result of setup mistakes that affect the entire batch. The larger the batch, the more items affected.

The classical way to determine optimal batch size is based on the economic order quantity (EOQ) formula:

$$\mathrm{EOQ} = \sqrt{2DS/H}$$

where:

D is demand
S is setup cost
H is holding cost

Since, traditionally, holding cost has been underestimated because it ignores the effects of batch size on quality and lead times, and since the setup cost, a direct function of setup time, is usually large, the formula (and managers' thinking) has been biased toward large batch production.

Once ways were found to make setups short and inexpensive, it then became possible for Toyota to economically produce a variety of things in small quantities. In other words, Toyota could produce any sized quantities, whatever demand dictated—even if demand was very small. The smallest size demand is one unit, and Toyota set the goal of being able to produce anything, one unit at a time. This is called **one-piece flow**.

Quality at the Source

Ohno saw that the traditional manufacturing practice of stationing inspectors at locations throughout and at the end of the line did little to promote product quality. Defects missed by inspectors were passed from one worker to the next. As a product was assembled, defects became progressively more embedded inside, and, thus, more difficult to detect. If detected, defective products were scrapped or sent to rework areas; if not, they were passed on to the customer. Thus, relying solely on inspectors was not a practical means to eliminate defects and the costs associated with making and reworking defects.

Ohno reasoned that to eliminate product defects, defects must be discovered and corrected as soon as possible, which means going to the source of defects and stopping them there. Since the workers are in the best position to discover a defect and immediately fix it, Ohno assigned each worker responsibility for detecting defects. If the defect could not be readily fixed, any worker could halt the entire line by pulling a cord (an **andon**). At first the Toyota line was frequently stopped and output was low, but over months and years of refining the process, the number of defects dropped, sources of errors were eliminated, and the quality of parts and assembled products improved. Eventually the quality of finished goods was so high that it practically eliminated the need for rework.

Equipment Maintenance

Manufacturing organizations laden with work-in-process (WIP) inventory are not much concerned about equipment maintenance because the inventory allows work to continue (for a while) even when equipment breaks down. Further, many organizations actually bank on equipment breaking down and carry enough inventory between operations to cover for that eventuality. Some managers are of the belief that the most productive way to run a machine is to run it constantly (three shifts if possible) until it breaks, then fix it. This philosophy runs square in the face of waste reduction because, accordingly, inventory is held, operations are idled during equipment repair, and repair costs are higher.

Consistent with the philosophy of worker empowerment at Toyota, operators are assigned primary responsibility for basic **preventive maintenance** since they are in the best position to detect early signs of malfunction. Specialists who formerly did maintenance now diagnose and fix only complex problems, train workers in maintenance, and improve the performance of equipment. The combination of maintenance specialists and workers both practicing preventive maintenance almost eliminates equipment breakdowns.

Pull Production

In traditional manufacturing plants, products are fashioned by moving batches of materials from one stage of the process to the next. At each stage an operation is performed on an entire batch. Because batch sizes and processing times vary from stage to stage and because usually there are several jobs that need to be worked on at each operation, it is difficult to synchronize the flow of material from one stage to the next. As a result, materials wait at each operation before they are processed; typically, the wait time far exceeds the processing time for the batch. Plant-wide the result is large amounts of WIP waiting at various stages of completion. In terms of inventory holding costs and lead times, the waste can be staggering.

To reduce these wastes, Ohno developed the **pull production** method wherein the quantity of work performed at each stage of the process is dictated solely by the demand for materials from *the immediate next* stage. Ohno also developed a system called **kanban** to coordinate the flow of materials between stages so that just as a container was used up, a full container from the previous stage would arrive to replenish it: This is actually where the term *just-in-time* originated. Production batches are kept small by using only small containers to hold and transport materials.

Although pull production reduces waste, it is, in truth, not always an easy system to implement. Toyota took 20 years to work out the process.

Standard Work

At Ford and most modern industrialized organizations, work standards developed by engineers and specialists specified what the frontline employees were expected to do. But the standards, developed by staffers somewhat detached from the actual workplace, were often unrealistic, impractical, and provided no motivation for improvement. Ohno, during his early years at Toyota, had developed the philosophy that workers should create their own job descriptions and work standards because, he reasoned, only then would they be able to fully comprehend the details of their work, know why things had to be done in a certain way, and be capable of pondering better ways to do it. He developed the concept of **standard work** or **standard operations** whereby worker teams create the standards that define the work they currently do. Standard work also serves as the baseline from which to stabilize processes and improve them to better adapt to changes in demand and the work environment. It became a key tool in continuous improvement.

Supplier Partnerships

Ohno recognized problems with traditional manufacturer–supplier relationships in the United States. Typically, the manufacturer would develop detailed specifications for each product part and then contract with suppliers to make the parts through a competitive process that, usually, awarded the lowest bidder. Multiple suppliers for each part were retained, and these suppliers were routinely played one against another to keep prices down.

Ohno saw the need for a different kind of relationship wherein the manufacturer treats its **suppliers as partners** and, as such, as integral elements of the production system. Essentially, suppliers are trained in ways to reduce setup times, inventories, defects, machine breakdowns, and so forth, in their own plants, and in return they take responsibility for delivering the best possible parts/services to the manufacturer in a timely manner. The number of suppliers for each part was greatly reduced, sometimes to only a few, and each would get a larger share of the manufacturer's business. With this arrangement, the manufacturer, suppliers, and the final customer all benefit.

Employee Involvement and Empowerment

In U.S. plants, there was a specialist for doing just about everything. Other than machinists and assembly workers, though, few specialists directly added value to a product. Ohno reasoned that most tasks done by specialists could be done by assembly workers and probably done better because assemblers were more familiar with the workplace. To this end, he organized his workers into teams and gave them responsibility and training to do many of the specialized tasks. Each team had a leader who worked as one of them on the line.

In addition to their assigned work tasks, teams were given responsibility for housekeeping and minor equipment repair. They were allowed time to meet to discuss problems and find ways to improve the process. Further, they were allowed to collect data to help diagnose problems, develop solutions and plans, and use suggestions from specialists who were still on hand but in relatively few numbers compared with those in Detroit. The notion of workers **asking why five times** to get to problem root causes was first introduced at Toyota. Eventually, worker responsibility was expanded to include many areas usually held by specialists, including quality inspection and preventive maintenance.

All of this relates to a key lean principle, one that has gone relatively unacknowledged, at least formally, and that is **respect for people.** (At Toyota, it is called respect for humanity.) Respect for people refers in particular to respect for *peoples' abilities*, and in TPS it is applied, supported, and promoted in numerous ways. People are provided training, coaching, and opportunities for development and personal growth. They are challenged to think and work at the peak of their abilities, and their decisions are trusted. The term "people" broadly applies to all stakeholders—customers, suppliers, and employees at every level and function of the organization. Respect for people is at the basis of lean methods and, more broadly, continuous improvement.

Continuous Improvement

A main reason for Toyota's success and rise to preeminence is emphasis on continuous improvement, which is embedded in Toyota's vision and goals, expectation of employees and suppliers, daily operations and management practices, and culture. At the corporate level, management sets challenging goals related to customer needs and wants, and these goals become the basis for setting challenging shorter-term targets throughout the company—challenging because they require continuous improvement of processes. Improvement through finding and removing barriers to targets is built into workers' daily routines and is guided and supported by standards and management. Elements of TPS such as reduced setups, small-lot production, and pull production *mandate improvement*; they expose obstacles—sources of waste—and challenge everyone to remove them. Management's role is to establish targets related to better satisfying the customer, and to coach and support the production system—especially its workers—to meet those targets. It is no stretch to say that the culture at Toyota *is* continuous improvement, and through that culture the company has moved from a position of disadvantage to world leadership, the result of an endless series of daily improvements made everywhere and at every level of the company.

By the early 1960s, Toyota Motor Company had worked out most of the major principles of lean production. Eventually, all other Japanese automakers adopted their own versions of TPS. In 1968, Japan surpassed West Germany as the number two producer of vehicles in the world; in 1980, it surpassed the United States to become number one. In 2016, Toyota became the world's largest automaker.

Training within Industry[14]

At the start of World War II, at the same time the U.S. government was conscripting a large segment of America's eligible workforce to fight, it was also mandating a crash industrial effort to produce war materiel—ships, planes, tanks, munitions, clothing, and so on. The immediate result was a massive shortage of experienced, skilled labor. To accelerate training the huge numbers of workers needed—hundreds of thousands and ultimately millions of them—the U.S. government created TWI, or training within industry. TWI provided standardized training methods to enable experienced supervisors to quickly and effectively transfer knowledge to their workers. It consisted of a series of job-training or "J-programs," each with manuals and a train-the-trainer segment so that newly trained workers could become trainers themselves and, thus, rapidly expand the size of the skilled workforce. The program was a great success and trained over 1.6 million workers in over 16,500 plants.

Job instruction (JI), the first of the TWI J-programs focused on methods for supervisors to develop their workers. It gave instructions for how to prepare workers to learn, demonstrate work, point out the key elements of a job, perform trials, and coach. Job methods (JM), the next J-program, taught supervisors how to scrutinize job methods so as to improve production output and quality using existing labor, material, and equipment, and with minimal or no outside technical or engineering advice. It focused on defining the steps in a production method, questioning their practicality, and improving the method through eliminating, combining, or simplifying of job steps. Another J-program, job relations (JR), focused on helping supervisors improve relations with workers so as be more effective at assessing problems, making decisions, and taking action through cooperation with workers. It emphasized leader skills such as providing constructive feedback, crediting workers, using workers to the best of their ability, and gaining loyalty and trust.

All of the J-programs emphasized that job methods should be standardized and repeatable because only in this way could job methods be trainable and sustainable.

After the war, the U.S. government took TWI abroad through consultants it had hired to teach European and Japanese companies business practices. In Japan, many companies embraced TWI, including Toyota where Taiichi Ohno and others incorporated it into TPS. Aspects of TWI to be found in TPS include standardized work and variation reduction, training by coaching and mentoring, process improvement using existing resources, work method simplification, problem-solving at the problem source, learning by doing, kaizen, and the plan-do-check-act (PDCA) scientific method.

In the meantime TWI in the United States was fading. Viewed as a means to help win the war, companies began abandoning the J-programs as soon as victory was evident, and they stopped almost completely when the government ceased TWI funding in 1945. TWI was rarely embraced by top management and had been adopted as necessary to meet the requirements of the military. Senior and middle managers had largely resisted TWI and were happy to see it vanish—perhaps because it moved the locus of decision making farther down the hierarchy or somehow diminished their stature and authority, even if only in perception.

America's Fall from Manufacturing Grace[15]

It would be a mistake to assume that Japan's economic success resulted solely from lean production. Japan is a very communal society, and after World War II the ministries of government decided where the nation's limited resources should concentrate to best serve the country. The nation's educational system put emphasis on turning out engineers. By creating an excess of engineers, it was thought, more of them could be put on the shop floor where they could tinker with improvement. The cumulative effort of so many talented people working on so many things was incalculable. It was also the case that, deprived of opportunities in aerospace, nuclear, and other cutting-edge technologies with military potential, the cream of Japan's technical brainpower was funneled into more prosaic industries such as autos, steel, and machine tools. In the United States, such industries were having trouble attracting the best people.

While the Japanese were developing improved methods of production, American manufacturers were being distracted. Beginning in the 1950s, a new breed of executives came to power. Here again the change was first seen at Ford, starting with the hiring of a group of young men known as the Whiz Kids, men who during the war had gained a reputation in the Air Corp for prowess in applying analytical techniques to military problems.[16] But the Whiz Kids were not car men, nor even product men. Lacking knowledge of products, they played up their "management systems," which emphasized financial criteria and (presumably) told management what to do, regardless of market, product, or industry. The group was at first a welcome relief at Ford. Henry Ford had distrusted accountants and fired most of them, so company records and procedures were in disarray. The Whiz Kids reorganized everything and imposed tight financial and accounting controls. They cleansed the system, though later people would question whether or not their kind of cleansing had been best. The issue is not the efficacy of financial management systems; such systems are an important component of modern management. What is wrong is that in the Whiz Kids' brand of management, financial controls dominate and smother all other components of business—marketing, engineering, and manufacturing.

At Ford and at most other corporations in the United States, a powerful new bureaucracy was installed, displacing the manufacturing people who had customarily dominated. Given that one of the easiest ways to bolster profit performance is to curtail capital expenditure and implement cost cuts, top management pared back on capital investment and product innovation, made cuts in facilities and labor, closed plants, and moved manufacturing overseas.

Over the next several decades, graduates of U.S. business schools swelled the ranks of the new elite. The best students went into finance and systems analysis, which had become the fast tracks to senior management. Rarely did they go into manufacturing, which was viewed as a dead end. It became rare in big companies to find a manufacturing person on the board or as president.

(Manufacturing in Japan carried higher prestige, and boards there had many men with factory experience.) As U.S. managers changed their style, they also changed their business agenda. Driving up the price of shares on the stock market became more important than making a good product with a profit.

In the meantime, through continuous improvement in products and, especially, processes, Japanese producers were slowly eroding U.S. market share in autos, steel, and electronics. Rather than learn from it, American managers used the challenge from Japan as a threat to keep wages down. They told workers, "You better take the contract we are offering you or see your jobs moved to another country."

Climbing Back

The Whiz Kids approach to management is still taught in business schools and practiced in corporations, but signs indicate that mistakes of recent decades are being recognized and corrected. There are also signs that U.S. manufacturing is on the road to becoming competitive once more. This is not to say that all is well in U.S. manufacturing or that America will regain its position of dominance in world production. Many executives still view manufacturing as but an expense that must be pared back or fully outsourced. The United States is still the most innovative country in the world, but its innovators often have a hard time getting financial backing at home and must look overseas where investors and manufacturers seem more eager to snap up promising new ideas. These manufacturers, of course, become the long-term beneficiaries of American innovativeness.

Modern Developments

To round out this brief history, we note some other manufacturing developments in the last five decades. These developments can be summarized in two words: computer technology. Since the 1970s, one of the greatest impacts the computer has had on manufacturing is in **material requirements planning** (MRP) systems that link together information about parts and components that go into a finished product and generate schedules and purchase orders to assemble and procure parts. Without the computer's capability to manipulate large quantities of data, coordinated scheduling and rescheduling of thousands of parts for producing hundreds of products would be impossible. These systems are often integrated with marketing, financial planning, customer relations, and supply chain management functions in company-wide enterprise resource planning (ERP) systems.

Other noteworthy developments are CAD, CAM, flexible manufacturing systems, computer-integrated manufacturing (CIM), and electronic data interchange. CAD enables designers to design a part or product and test its features and compatibility with other parts and products, all with a computer. CAM refers to software that translates design requirements into instructions for controlling production machinery. Given CAM's dependence on CAD for input, CAD/CAM is often applied as a single, integrated system.

A **flexible manufacturing system** (FMS) aims to achieve high-variety output at low cost. Although an FMS can be manual, the usual notion of FMS is a computer-controlled, automated system. A large FMS consists of many machines or processes, each with varying degrees of mechanization, linked by automatic transfer systems, guided vehicles or robots, and all controlled by a central computer. With a computer regulating changes in machine settings, parts, and tools, one machine can perform numerous functions, and requires very little time for changeover between parts.

The next step beyond FMS is CIM, which links CAD/CAM; automated material handling; robotics; and automated manufacturing planning, control, and execution systems into a single, integrated system.

Electronic data interchange (EDI) refers to computer-to-computer exchange of information, usually meaning between multiple companies. EDI enables quick, accurate sharing of production schedules and placing of orders between customer–supplier companies.

Computer technology is also responsible for another aspect of mass manufacturing: mass customization. In one scenario, a sales clerk at a clothing store enters a customer's vital statistics into a computer to create a digital blueprint of a pattern, which is transmitted to the factory and instructs a robot to cut the fabric to precise measurements.[17] In another scenario, customers phone an engineer to discuss the kind of part they need, and the engineer enters the specifications into a CAD/CAM system to design a one-of-a-kind part. Overnight, automated machines grind out the custom parts. High-end car manufacturers offer similar service. Buyers of Tesla electric cars can customize an entire car by choosing options for batteries, seats, sound systems, and so on, online, then pick up the car a few weeks later at the dealer.

On the near horizon but approaching rapidly are other technologies that will change the face of manufacturing. Two examples are **additive manufacturing** and the **Internet of Things** (IoT). With additive manufacturing, popularly called 3-D printing, a product is made layer by layer, either with a printer-like device or by cold spraying—blasting particles through a nozzle at high speed so the particles bind and form shapes. Additive manufacturing is the equivalent of painting a 3-D object into existence. Such technology can produce products in high volumes or as few as one using a variety of materials such as plastics, ceramics, metals, and even wood. It can even layer more than one material and create sophisticated components that incorporate circuitry and sensors.

IoT refers to electronic devices interconnected and communicating with each other via Internet infrastructure without human intervention. IoT's greatest impact on manufacturing will be on sensing, measurement, and process control. Devices embedded in systems, machines, and products will capture, record, and share data about, for example: Temperature and humidity; the location of a machine, vehicle, or product; the potential failure of a machine; and the characteristics of parts being manufactured. They will share data and communicate with each other, or with humans via, for example, a cellphone. Devices connected through IoT will not only guide "smart" machines and robots but provide information to manage and control processes and entire factories. IoT technology offers opportunities to improve product quality, workplace safety, equipment reliability and scheduled preventive maintenance, and supplier coordination—all important aspects of lean production.

In many industries, technologies like these have cut labor, material, transportation, and inventory costs, and have improved manufacturing cycle time, flexibility, product quality, and customer satisfaction. In other cases, however, because the technologies were too costly, poorly implemented, prematurely made obsolete, or ill-suited for the operation, they helped little or made things worse. In a study of FMSs used in companies in the United States and Japan, it was revealed that while the average U.S. FMS was used to produce ten types of parts, the Japanese FMS produced 93. Said the researcher who did the study, "With few exceptions, the flexible manufacturing systems installed in the United States showed an outstanding lack of flexibility."[18]

It is crucial to point out that none of the manufacturing developments described constitute lean production. Such developments might improve the performance and competitiveness of any organization, but none of them alone imply or necessarily support a culture of continuous improvement and waste elimination. All offer opportunities to aid in lean production, but ultimately, they are just tools and none involve the fundamental changes to worker and manager roles and supplier relationships necessary for lean production.

The Imperative

Programs to implement lean production methodologies have been undertaken by organizations everywhere. Despite variations in these programs, the fundamental ingredients of all of them—the tools of lean production—remain largely the same. In manufacturing, many of these tools represent a departure from traditional ways, although many of them also conform to principles of good operations and manufacturing management that have been in the books for decades. Some are technically and culturally difficult to implement, and some provoke resistance from managers and workers. As a result, programs to adopt lean production methodology require long-term commitment to implement, and few of them will show positive results in the first several months or even years of effort.

The alternative to not adopting these methodologies, however, is potentially disastrous. Players who have successfully adopted the methods of lean production and who faithfully apply these methods to improve their processes and products have gained a substantial competitive advantage over others within the same market who continue to operate by the old rules of mass production.

The proof is in the record. It is not an overstatement to say that companies that have been challenged by producers committed to the principles of lean production have been able to meet or beat back those challengers only by committing to the same principles. Companies that were challenged but that did not become lean producers, either because they ignored the challenge or did not have time to make the transition, lost; either they chose to drop out of the market, or they were forced to drop out.

Organization of the Book

This book is divided into four sections. Section I (Chapters 2–4) is an overview of three concepts fundamental to lean production philosophy and practice: **continuous improvement**, **elimination of waste**, and **focus on the customer**. Survival and competitiveness in manufacturing mandate continuous improvement of products and processes—forever striving to be better, faster, cheaper, and more agile. Continuous improvement of processes happens largely through identifying wastes in the process and eliminating them. This part of the book begins with an overview of the strategic importance of continuous improvement, kinds of improvement, wastes and their sources, and basic lean principles for waste reduction and process improvement in manufacturing.

In the pursuit of competitive advantage, a company must target its improvement efforts, which is where the concept of quality comes in. In the notion of **customer-focused quality**, customer-defined requirements are used to set priorities for all improvement and waste-reduction efforts. The related topics of **total quality management**, **statistical process control,** and **Six Sigma quality** are also covered in Section I.

Section II (Chapters 5–13) covers the main tools of lean production for process improvement. In a typical company, waste exists in the form of product defects, inventory, overproduced items, idle workers and machines, and unnecessary motion. Through lean production practices, it is relatively easy to identify these wastes and eliminate them. This section of the book presents the core practices of lean production, namely, producing in **small batch sizes**; reducing process and equipment **setup times**; **maintaining** and **improving equipment**; using the **pull system** (kanban) for production control; organizing facilities into **focused factories** and **work cells**; **standardizing work** on the shop floor; eliminating manufacturing defects, the notion of **pokayoke** or mistake-proofing; and creating new processes that leapfrog the old, called **production preparation process**.

The tools and methodologies in this section are interrelated, and successful implementation of any one is predicated on implementation of many of the others. In every case, the methodologies are aimed at institutionalizing the process of continuous improvement. In every case also, worker associates play a central role. This role and implementation issues are also addressed in this section of the book.

Section III (Chapters 14-17) reconsiders the lean production concepts introduced in earlier chapters in the context of a working manufacturing system. Assuming the elements of lean production are well along into implementation, the question then is, "How is production planned and scheduled to take the fullest advantage of these elements?" This section of the book takes a step back to look at lean and pull production methods as elements of a total production system, one that forecasts demand, accumulates orders, translates forecasts and orders into plans and schedules, authorizes material procurement, and executes work tasks to ultimately yield a finished product. Particular topics of this section of the book include the concepts of **production leveling** to smooth fluctuations in production plans and schedules, **balancing capacity** and **synchronizing of operations**, and a **framework of overall planning and control** to tie together many of the topics from elsewhere in the book. Section III also addresses the relative roles of centralized systems and decentralized (shop floor) systems in lean production planning and control, and the subject of adapting MRP systems to pull production.

The quality, cost, and delivery performance of every manufacturer depends in large part on the performance of its suppliers. The last chapter of Section III addresses the concept of **supply chain management** and applications of lean concepts therein to improve performance and reduce waste throughout all suppliers and connecting routes.

Section IV (Chapters 18 and 19) covers **daily management** and **strategy deployment,** topics that address the issues of (1) how to meet daily work goals and retain the gains from prior improvement efforts (and not backslide to old ways) and (2) how to ensure improvement efforts are meaningful and assist the organization in achieving its objectives and long-range goals. Many experienced practitioners express that the methods and processes discussed in this section are among the most difficult of everything about lean to implement. They are placed at the end of the book because in most companies they are implemented later—a few years or so after the company has become familiar with other lean tools and practices and adopted a philosophy of continuous improvement and waste elimination. But the implementation cannot be delayed too long since without daily management, improvement gains might be lost.

Readers will notice a distinct shift in the focus of Section IV from the rest of the book, from shop-floor matters to management matters, and particularly to managers' roles and responsibilities in day-to-day monitoring and control of operations (daily management) and annual and long-range strategic planning.

Originated and developed in manufacturing, the philosophy and tools of lean production have since been widely adopted in all kinds of organizations to improve processes and eliminate waste. To illustrate lean production practices as applied to a wide variety of service and manufacturing situations, many examples will be given throughout the book.

Questions

1. Explain how each of the following is a basis for competitive advantage in manufacturing: cost, quality, time, agility.
2. Distinguish between delivery time and time to market.

3. In ten words or less, what is the primary focus of lean production?
4. What is meant by the term *production pipeline*? What does the production pipeline have to do with lean production?
5. What features differentiate lean organizations from other organizations?
6. What is craft production?
7. What is mass production?
8. What were Henry Ford's most significant contributions to mass production?
9. Why did Eiji Toyoda and Taiichi Ohno decide against copying Detroit's system of mass production? How did that lead to the TPS?
10. Describe the principles of the TPS and how it is a departure from traditional production systems.
11. Explain some of the reasons why America's position as the world's supreme industrial power began declining in the 1960s and 1970s.
12. What is the relationship between quality and production in craft production?
13. What effect did interchangeability of parts have on product quality?
14. Why have overseas corporations been successful at capturing large shares in U.S. markets? What is the role of manufacturing?
15. What are some potential barriers against adopting industrial policies and manufacturing practices in the United States that would help make American industry more competitive?
16. A principal feature of lean production is large-scale employee involvement and employee empowerment. What do these concepts mean? Why in practice are they considered somewhat radical in U.S. organizations when they are accepted as commonplace in Japanese organizations?

Research Questions

To answer these questions, complete a literature search and include material beyond this chapter.

1. Name some newsworthy, contemporary companies that are successful (high market share, high profits, leading-edge products, and so on). Which of them are "turnaround companies" (rebounded after hard times)? Which of them are lean companies?
2. What are some big-name companies that in recent decades stopped producing certain products after Asian or European producers aggressively entered the market? Which of these Asian or European producers use lean practices?

Suggested Reading

Dennis, P. 2007. *Lean Production Simplified: A Plain-Language Guide to the World's Most Powerful Production System*, 2nd ed. New York, NY: Productivity Press.

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Ohno, T. 1988. *Toyota Production System: Beyond Large-Scale Production*. New York, NY: Productivity Press.

Womack, J., Jones, D., and Roos, R. 1990. *The Machine that Changed the World*. New York, NY: Rawson.

Notes

1. Kearns, D. and D. Nadler. 1992. *Prophets in the Dark: How Xerox Reinvented Itself and Beat Back the Japanese.* New York, NY: Harper Business.
2. Roth, A., A. DeMeyer, and A. Amano. 1989. International manufacturing strategies: A competitive analysis, In *Managing International Manufacturing,* ed. K. Fellows, Amsterdam: Elsevier Science, 187–211.
3. National Center for Manufacturing Sciences. 1990. *Competing in World-Class Manufacturing.* Homewood, IL: Business One Irwin, 118.
4. A related philosophy is **time-based competition** (TBC), which, obviously, puts more emphasis on the time criterion. Much of the practice of TBC overlaps with TQM and JIT practices, although an express goal of TBC, one which is not necessarily a goal of JIT or TQM, is to shorten product development times (to improve "agility" in terms of product redesign and innovation). See P. Smith and D. Reinertsen. 1991. *Developing Products in Half the Time.* New York, NY: Van Nostrand Reinhold); and J. Blackburn. 1991. *Time-Based Competition.* Homewood, IL: Business One Irwin.
5. Schonberger, R. 1986. *World Class Manufacturing: The Lessons of Simplicity Applied.* New York, NY: The Free Press, 137.
6. Dahlgaard, J. and S. M. Dahlgaard-Park. 2006. Lean production, six sigma quality, TQM and company culture. *The TQM Magazine* 18, no. 3: 263–281.
7. The analogy has been used before. See Mather, H. 1998. *Competitive Manufacturing*. Englewood Cliffs, NJ: Prentice Hall, 12–20; Sandras, W. 1992. *Just-in-Time: Making It Happen.* Essex Junction, VT: Oliver Wight, 7–8.
8. Material in this section is derived from two principal sources: Womack, J., D. Jones, and R. Roos. 1990. *The Machine That Changed the World.* New York, NY: Rawson; and Halberstam, D. 1986. *The Reckoning.* New York, NY: Avon Books.
9. See Lazonic, W. 1990. *Competitive Advantage on the Shop Floor.* Cambridge, MA: Harvard University.
10. Ford's innovative contribution to the interchangeable part was in its application and execution: He imposed on all suppliers of each part a single standard to which they were all expected to conform.
11. DuPont and Carnegie Steel also developed new forms of organization. DuPont was the first to establish corporate divisions, and Carnegie was the first to vertically integrate an industry—raw materials to finished product. The point: It was US companies that were making the innovations. Nothing like it was happening in Europe.
12. The family name Toyoda means "rice field" in Japanese; the word Toyota, which they chose to call the corporation, has no meaning.
13. Womack et al. 1990. *The Machine That Changed the World,* 53.
14. Sources: Huntzinger, J. 2002. Roots of Lean—Training Within Industry: The Origin of Kaizen. *Target,* 18(2): 9–22; Huntzinger, J. 2006. Why standard work is not standard: Training within industry provides the answer. *Target*, 22(4): 7–13.
15. This section is derived from Halberstam, *The Reckoning*.
16. See Byrne, J. 1993. *The Whiz Kids.* New York, NY: Currency Doubleday.
17. Rifkin, G. 1994. Digital blue jeans pour data and legs into customized fit. *New York Times.* November 8: A1.
18. Jalkumar, R. 1986. Postindustrial manufacturing. *Harvard Business Review.* November–December: 69–76.

I

CONTINUOUS IMPROVEMENT, WASTE ELIMINATION, CUSTOMER-FOCUSED QUALITY

The term **improvement** implies that something about a process has changed for the better. In business operations, improvement is often expressed in terms of changes in process output or input. For example, increasing the process output–input ratio (O/I) is considered improvement, achieved by either an increased level of output for a fixed level of input, or by a reduced level of input for a fixed level of output. Though more output for the same input or the same output for less input are common ways of measuring improvement, too often the view of what constitutes input and output (and, hence, improvement) is narrow and simplistic. Real improvement represents an attempt to make something better while trying to minimize cost and adverse consequences. For example, if a manufacturing process is changed to increase the rate of output, the change represents an overall improvement only as long as aspects of the output or other processes have not been degraded. If the change results in diminished product quality, increased production cost, worsened working conditions, or increased toxic wastes, the increased output may not be an improvement at all.

In the global marketplace, the concept of improvement is synonymous with "never stop trying." External factors (technology, resource availability and costs, and competitors' capabilities) over which an organization has little control but that influence its competitiveness and profitability are constantly changing. Inside the organization, factors like work conditions, employee motivations and skills, and processes are changing too. As a result, whatever was good enough yesterday will probably not be good enough tomorrow.

In addition, there is no logical end to customers changing their expectations, neither in level or direction, nor to what competing organizations will do to try to meet those expectations. Thus, there can be no such thing as ultimate improvement. Organizations that try to achieve ultimate improvement or are content with staying in one place will be surpassed by others keeping pace with changes. In short, survival and success mandate **continuous improvement**.

Paralleling the idea of continuous improvement is the concept of **elimination of waste**. To use a metaphor, the road to improvement is potholed with waste. Like potholes, sources of waste are everywhere and no matter what you do, they keep coming back. Any attempt to improve a process by increasing output with a fixed level of input or by maintaining the same output from reduced input implies that the process contains waste. Part of continuous improvement is the drive to continuously identify waste and eliminate it.

In the pursuit of competitive advantage, an organization must be able to target its improvement and waste-elimination efforts. It must have a scheme for prioritizing where to expend time, effort, and resources in its improvement and waste-reduction efforts; this is where the concept of quality comes in. In seeking competitive advantage, **customer-focused quality** is the criterion an organization uses for prioritizing improvement and waste-reduction alternatives. Quality has a price, however; thus, efforts devoted to increasing quality must be accompanied by efforts to hold or reduce costs. Lower cost is one of the many byproducts of eliminating waste in a process.

To avoid getting into a semantical debate about distinctions between the concepts of improvement, elimination of waste, and customer-focused quality, let us just say they are all related, which is why they are discussed together here. The concepts and their relation to each other, to lean production and total quality management (TQM), and to competitive manufacturing are topics of the chapters in Section I:

Chapter 2: Fundamentals of Continuous Improvement
Chapter 3: Valued Added and Waste Elimination
Chapter 4: Customer-Focused Quality

Chapter 2

Fundamentals of Continuous Improvement

> Even if you are on the right track, you'll get run over if you just sit there.
>
> **Will Rogers**

> A rut is a grave with the ends knocked out.
>
> **Laurence Peter**

An organization's ability to survive and thrive depends on how well the organization adapts to demands imposed by a changing environment. Organizations come and go, though relatively few outlive the people who have worked in them. Organizations that survive for a century are rare. Nowadays it seems that big companies whose names were once synonymous with power and prosperity are being eclipsed at a quickening rate; their demise is hastened by a failure to adapt.

The challenge of change in a business environment comes along many fronts: Competitors introduce new products, industries develop new processes and technologies, and the scope of the business environment expands. One time, not so long ago, a business could feel safe if it had captured most of the market from its domestic competitors. Today, no organization anywhere can feel safe just by having beaten domestic rivals. The business environment has expanded to put U.S., Asian, and European organizations in direct competition, and this competition has changed the definition of what constitutes doing a good job. Organizations everywhere are always striving to offer something new and, as a result, customer expectations are always expanding, and satisfaction tends to be a fleeting phenomenon. A company's survival and success now depend on its ability to **continuously improve** its products and services to meet and exceed customer expectations.

Continuous improvement is measured in terms of producing things better, faster, and cheaper, and being more agile. But to improve products and services it is necessary to go beyond the products and services themselves; it is necessary to examine and improve the materials and basic processes intrinsic to them. Continuous improvement is thus synonymous with **continuous process improvement.**

Lean production is, effectively, about continuous improvement, so this chapter sets the stage for everything to follow. The chapter starts by discussing continuous improvement and what it means to be *continuous*. Also discussed is the role of frontline employees in improvement efforts, and different improvement approaches such as PDCA (plan–do–check–act), value analysis, kaizen projects, and value stream mapping (VSM). The chapter concludes with a review of the seven basic problem-solving and analysis tools.

Continuous Improvement as Tactics and Strategy[1]

A premise of continuous improvement is that processes and products can be improved without limit. Yet we know intuitively there must be limits, if only because improvements require resources, and resources are limited. Part of continuous improvement involves knowing where to direct improvement efforts so they contribute the greatest good. This means being able to identify the portions of the system that contribute most to increasing product quality and meeting customer requirements, as well as the ability to recognize when a product or process is already as good as it can be.

Incremental Improvement: Kaizen

The concept of limits to improvement can be described in terms of the S-curve shown in Figure 2.1. The curve shows the relationship between the effort or resources to improve something and the incremental result of that effort. The kind of improvement represented by the S-curve is called **incremental improvement**, which is the process of making something better through the accumulation of small, piecemeal improvements, one at time.

At first, progress is slow, hence, the early part of the curve is nearly flat. As the object under scrutiny is better understood, however, learning accelerates and improvement occurs at an accelerated rate. The idea that great improvement eventually comes from a series of small, incremental gains is the Japanese concept of **kaizen**. Accordingly, employees throughout the organization patiently work to continually improve the processes in which they are engaged. Through a coordinated series of ongoing kaizens, many small improvements result in big changes.

Incremental improvement can, over time, lead to substantial improvement, although, as the S-curve illustrates, at some point that improvement will slow. Regardless of effort, improvement gains get smaller and smaller. Only so much can be done economically to improve something,

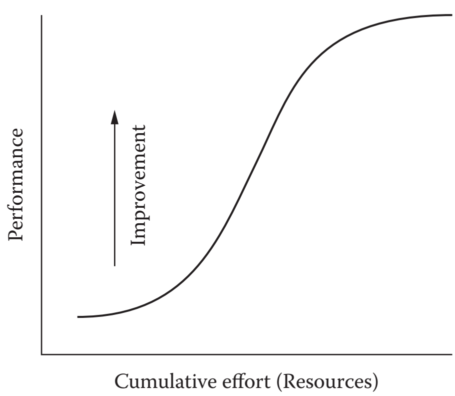

Figure 2.1 The S-curve of incremental improvement.

after which any residual improvement comes only at great expense. This concept of improvement has universal applicability, no matter the product or process.

What happens when the improvement threshold is reached? Does improvement cease? For an existing technology, product, or process, the answer is yes, at least for now, because the cost of further gains becomes too great. This is important to note because it means that if further improvement is necessary for the organization to survive, then something new and perhaps radically different is also necessary.

Innovation Improvement

Once the limit is reached, higher performance is achieved only by adopting a new way or new technology (something fundamentally different and innovative, something that does not have that performance limit). This is called **innovation** or **breakthrough improvement**. This new way has its own S-curve, shown as the curve on the right in Figure 2.2. Figure 2.2 illustrates the difference between two improvement approaches: The continuous, incremental approach is represented by a

CASE IN POINT: LCD TECHNOLOGY AT RCA AND SHARP

A good example of traditional U.S. and Japanese kaizen approaches to improvement is Hedrick Smith's discussion of the history of the liquid crystal display (LCD).[2] In 1968, RCA unveiled a new technological discovery, the LCD, a flat-display screen that promised to replace cumbersome cathode-ray tubes in TV sets. To transform the new technology into useful products, however, would take years of patient developmental work and considerable financial investment, neither of which RCA's corporate culture supported. In fact, RCA at the time was diversifying into areas like car rental, carpeting, and TV dinners because these provided quick returns, despite taking away funds from RCA's core business: electronics. Unlike founder David Sarnoff, who appreciated technology and pushed for innovation, RCA at this time was run by marketing and financial people who cared more about corporate stability and short-term financial success than industry leadership. After a half-hearted effort at producing LCD wristwatches and calculators, RCA sold its LCD patents to the Japanese in 1973.

Contrast this with what happened at Sharp in Japan. Sharp, at the time a modest-sized radio and TV producer dwarfed by RCA, saw a market niche in lightweight, energy-efficient LCD pocket calculators. It put $200 million into development, and the calculators became a market success. Profits from the calculators provided Sharp a springboard into other LCD and flat-panel display applications. Ultimately, Sharp invested a billion dollars in developing LCD technology and building plants to manufacture flat-panel displays.

Today LCD technology is everywhere—in industrial gauges, clocks, phones, TVs, computers, medical imaging systems, automobile dashboards, and aircraft cockpit controls, to mention a few applications. By the 1990s, Sharp and 18 other Japanese firms controlled 95% of the world market for flat-panel displays, although more recently Korea and Taiwan vie with Japan for LCD dominance. Many U.S. manufacturers have become dependent on LCDs, and Japanese producers have opened assembly plants in the United States to avoid tariffs. Total market revenues for flat-panel displays and associated electronics by 2007 were $42 billion.

As for RCA? All it got from the LCD was what it sold the patents for: $2 million.