“What every business leader and manager needs to know about Factory Physics science and logistics.” —**William “Gus” Pagonis, Lt. Gen. U.S. Army** (Retired), **former EVP for Supply Chain, Sears**

STRATEGY EXECUTION PROFIT

FACTORY PHYSICS

How Leaders Improve Performance in a Post—Lean Six Sigma World

FOR MANAGERS

Edward S. Pound • Jeffrey H. Bell • Mark L. Spearman, PhD

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McGraw Hill Education

New York Chicago San Francisco Athens London Madrid
Mexico City Milan New Delhi Singapore Sydney Toronto

ISBN: 978-0-07-182261-9

MHID: 0-07-182261-5

The material in this eBook also appears in the print version of this title: ISBN: 978-0-07-182250-3, MHID: 0-07-182250-X.

eBook conversion by codeMantra
Version 2.0

To Meg, my one and only, Zachary, Madeline, and Audrey—epiphanies to me. Every breath is a blessing. May the Peace of Christ that passes all understanding keep your hearts and minds in the knowledge and love of God.
—Edward S. Pound

To my wife, Julia; my parents; and the team at Arc Precision.
—Jeffrey H. Bell

To my wife, Blair, who for thirty years now has picked me up when I was low, has kept me humble when I was haughty, and has loved me always. And to my children, who have blessed me and taught me more than I have taught them: Jacob, William, and Rebekah; and to my grandchildren, a wonderful blessing, Alana, and Jake. And to the only wise God be glory forevermore through Jesus Christ! Amen.
—Mark L. Spearman

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Prologue

THE BOOK IN BRIEF

How can executives and managers of manufacturing and supply-chain companies predictably achieve high cash flow, low cost, and excellent customer service? This book describes how forward-thinking managers use Factory Physics science to cut through the clutter and confusion of competing options. Typical management efforts currently lack any comprehensive, practical science and are almost always hit or miss. Managers commonly move from one initiative one year, such as “Reduce inventory!” to another the next year, such as “Improve customer service!” because they don’t have a practical understanding of the underlying natural behavior of the operations they are trying to manage. Meanwhile, software companies are ever touting the next big initiative in software, such as materials requirements planning (MRP), enterprise resources planning (ERP), advanced planning and optimization (APO), cloud computing, and big data, to chronologically name a few, as if more advanced technology is the solution to whatever ails a company. Using *Factory Physics for Managers*, leaders will advance management practice and performance because Factory Physics science objectively describes what will work for them and what will not. The practical Factory Physics approach helps managers decide whether and when to use the excellent Lean, Six Sigma, and Theory of Constraints operations tools to drive company business strategy implementation while predictably and repeatedly achieving their business goals. Managers innovatively use Factory Physics science to drive higher performance using existing ERP or legacy information technology (IT)—no major IT investments required.

With *Factory Physics for Managers*, Ed Pound and Jeff Bell, executives each with over 20 years of experience in operations, and Dr. Mark Spearman, with over 30 years of experience in research and consulting and coauthor with Wallace Hopp of the world-renowned, award-winning textbook *Factory Physics* (Long Grove, IL: Waveland Press, 2008), describe the manufacturing and supply-chain management summit: a comprehensive, practical, and scientific approach to managing manufacturing and supply-chain operations. This approach directly addresses the inherent variability and risk in business. Typically, executives apply some bundle of popular initiatives, mathematics, and software—the results are unpredictable and often disappointing. This book provides a fundamental science in a very practical framework that will immediately improve executives’ and managers’ intuition, change how they view their world, and enable them to lead their organizations much more effectively.

WHY IS THIS BOOK NEEDED?

There is widespread confusion about what works and what doesn't work in manufacturing and supply-chain operations. As a result, operations strategies and plans often do not achieve what they promise. Software companies sell applications that just perpetuate what clients already do—regardless of whether or not the software does what the client needs. Lean proponents promote the Toyota Production System and its tenets in the vein of an operations theology. Six Sigma proponents insist on the rigorous statistical analysis required to identify and root out variability. Theory-of-Constraint adherents continue to focus exclusively on bottlenecks. In response to the uneven success of these efforts, Lean and Six Sigma proponents simply concatenate those two initiatives (Lean Six Sigma) in a continuing search for a comprehensive solution to achieve business results. Meanwhile, the academic community, and industrial engineering in particular, has lost its way. Many curricula teach the Lean and Six Sigma approaches but are following industry rather than leading. All this creates enormous confusion. What are executives or managers of manufacturing, service, or supply-chain companies to do in determining how to best lead their companies to achieve marketing and financial goals?

Wally Hopp and Mark Spearman, both with degrees in physics, had a firm grounding in the scientific method when they started as assistant professors in industrial engineering at Northwestern University in the 1980s. They surveyed the state of the field and wondered about a basic applied science and mathematical framework to describe operations. Most of the field was too deep and technical—operations research—or too unstructured and smacking of folklore—continuous-improvement zealotry—to be of good, sustainable use to manufacturing, service, and supply-chain executives. They set out to describe a fundamental, practical science of operations in a manner that would be useful to executives leading operations in support of a business's marketing and financial goals. One executive attending a nascent training session observed, "This is like physics of the factory," and the name Factory Physics stuck.

Messrs. Bell and Pound were students of Spearman and Hopp in Northwestern's MMM program in the early 1990s when the book *Factory Physics* was written. In 2001, Dr. Spearman left academia and devoted his time exclusively to industry and perfecting the science in practice. The authors have applied the principles relentlessly in companies large and small and have advanced the science to elegant leadership practices—both simple and effective. The result is the Factory Physics framework.

This framework shows that vague strategies such as "Eliminate waste" and "Reduce variability" are so general as to be nearly useless—except for companies that have done little or nothing for operations improvement. In the case of companies just starting their journey to systematically improve performance, there's usually so much waste and variability that merely focusing an organization's attention on those issues will generate good results. Beyond initial efforts, limited practical understanding of the Factory Physics science of operations often produces tremendous wasted effort and uneven results. Sound Lean and Six Sigma methodologies are often misapplied. Moreover, most manufacturing and supply-chain operations have high complexity as a result of product mix, process intricacies, and demand variability. This complexity cannot be handled effectively with simple Lean techniques such as value-stream mapping or 5S. Using simple techniques to handle complexity is like paying a financial advisor to tell you to “buy low and sell high.” In addition, how does copying another company’s best practices provide a *unique* competitive advantage? While the Toyota Production System works very well for Toyota and similar operations, there are better approaches for running a chemical plant or a job shop.

The Factory Physics framework enables managers to calculate risk and act decisively. They make operational decisions that are tuned to and inform their company’s business strategy to ensure success in operations leadership. The strength of the Factory Physics approach is that it is based in science. It is not “initiative by imitation” or something managers think they might try because a friend, or colleague, or an industry analyst said that it worked somewhere else. Executives and managers reading this book will be inoculated against the lull of bland slogans through an improved knowledge of operations behavior from the practical science learned. The book will explore that science in a plain and uncomplicated fashion. It will discuss some of the math behind the science at a basic level (those interested can refer to *Factory Physics* for a more mathematical discussion). *Factory Physics for Managers* will take the concepts and apply them to the task of designing and executing operations control to achieve a company’s business goals. The closed-loop control approach described for operations strategy and execution is fundamentally different from most, if not all, contemporary approaches. It will fundamentally transform a company’s information technology practices from transaction tracking “financial ERP” to an integrated control system connecting executive strategy to day-to-day execution. Additionally, the book addresses the change-management challenges that every executive faces. After reading this book, executives and managers will be much better prepared to lead. They will have much improved intuition and be able to apply practical science to translate business strategies into operations tactics and controls—tactics and controls that can be executed with confidence to achieve a company’s marketing and financial goals.

CHAPTER 1

Science—Use It or Lose

There is nothing more practical than a good theory.

—Kurt Lewin

"Oh, that is just a theory!" When we hear this, it usually means that the speaker thinks that the theory in question is not true and not useful. Indeed, the word *theoretical* has come to mean an idea that is not practical. The U.S. National Academy of Sciences' definition of *theory*, however, addresses this issue:

> *The formal scientific definition of theory is quite different from the everyday meaning of the word. It refers to a comprehensive explanation of some aspect of nature that is supported by a vast body of evidence. Many scientific theories are so well established that no new evidence is likely to alter them substantially. For example, no new evidence will demonstrate that the Earth does not orbit around the sun (heliocentric theory). … One of the most useful properties of scientific theories is that they can be used to make predictions about natural events or phenomena that have not yet been observed*.[1]

Interestingly, almost everything people do is based on some kind of theory—most aspects of which are intuitive. People intuitively believe that the floor will remain solid when they walk on it—that is a theory. Drivers intuitively believe that the car will slow down when they hit the brakes—another theory. If the brakes are broken, the theory is wrong, and the consequences can be severe. As the U.S. Academy of Sciences says, "The most useful property of a theory is *the ability to make predictions about natural events … that have not yet been observed*" [emphasis added].

But not all theories are good. Some are simply false. For instance, the theory that the Sun moves around the Earth is not true; instead, it is the other way round. Other theories may be true but really tell us nothing. These are known as *tautologies*. For instance, "All time in a factory is either value-added time or non-value-added time." This is just as valid as the statement, "All time in a factory is either spent in the cafeteria or not spent in the cafeteria." Because the truth of the statement is contained in the statement itself, it tells us nothing about the real world.

OF THEORIES AND BUZZWORDS

There are many theories about production management. However, managers usually don't argue about theories per se because they do not want to sound too theoretical;

instead, managers often argue about *buzzwords*. Merriam-Webster online defines a *buzzword* as "an important-sounding usually technical word or phrase often of little meaning used chiefly to impress laymen."

However, some truly remarkable innovations occurred at the beginning of the twentieth century, before buzzwords became common. *Mass production* was developed by Henry Ford. *Scientific management* was pioneered by Frederick Taylor and Frank and Lillian Gilbreth. And by the 1930s, *quality control* became important with the invention by Walter Shewhart of the control chart. Interestingly, many of these innovations morphed into buzzwords once the use of the computer began to take off in the 1960s. The first was as manufacturing requirements planning (MRP), followed quickly by the more encompassing manufacturing resources planning II (MRP II), business resources planning (BRP), and others. The 1980s introduced just in time (JIT), total quality management (TQM), business process reengineering (BPR), flexible manufacturing system (FMS), and a host of other three-letter acronyms (TLAs) (see Table 1-1). In the 1990s, a new TLA appeared: the all-encompassing enterprise resources planning (ERP) system. The 1990s also introduced two new buzzwords that were not TLAs and, given that they are still on the scene today, have had great endurance—*Lean* and *Six Sigma*. Indeed, given the success of Lean and Six Sigma, they are more like the historic initiatives of the early twentieth century than like the buzzwords of the 1980s and 1990s. What makes them different?

TABLE 1-1. Examples of Three-Letter Acronyms

TLA	Full Phrase	Description
MRP	Materials Requirements Planning	Computer software for production planning and control
MRP II	Manufacturing Resources Planning	Next generation MRP
BRP	Business Requirements Planning	Another extended version of MRP
FMS	Flexible Manufacturing Systems	Highly automated production system that can switch to different products quickly
BPR	Business Process Reengineering	An approach for redesigning work processes
JIT	Just In time	A production management approach for quick delivery
TQM	Total Quality Management	Management approach to improve quality of products and processes

Lean took the best of JIT and combined it with practical methods such as value stream mapping (VSM) and 5S. Numerous “how-to-do-Lean” books made Lean more than a buzzword—it became a phenomenon. Today, Lean is being applied in everything from factories to offices and even hospitals; the participating organizations perform scores, if not hundreds, of *kaizen* events (improvement projects) each year.

The other methodology with staying power has been Six Sigma. A common saying before Six Sigma was “KISS—Keep it simple, stupid!” But Six Sigma dismissed this axiom, recognizing that manufacturing systems are anything but simple and sometimes require a more sophisticated approach. That Six Sigma unapologetically applies extremely sophisticated statistical methods shows how far management has moved from KISS. Like Lean, Six Sigma has become almost universal, with most companies having trained numerous *black belts* (a more captivating name than “statistics expert”) and performing hundreds of Six Sigma projects each year. The fact that Lean Six Sigma is now being used by the U.S. Department of Defense and other government agencies indicates how ubiquitous it has become.

If you are looking for the next great buzzword, this book is not for you. If you are looking for a book that will tell you when and why Lean and Six Sigma work well as well as when and why they will not work, then read on. If you are looking for a book that allows you to understand the basic principles of production and supply chain so that you can design a management system that may or may not look like Toyota or Apple but is uniquely suited for *your* particular business environment, read on.

While we appreciate and strongly support the appropriate use of Lean and Six Sigma techniques, no matter the label, we have found that Lean and Six Sigma approaches do not provide a *comprehensive* theory for managers to use in charting a course for business performance. Additionally, there are some principles of Lean and Six Sigma theory that consider neither the reality of the business environment nor the natural behavior of production/inventory systems. Very often, Lean practitioners consider the Toyota production system with its focus on achieving one-piece flow as the *end* rather than as a *means* to the ultimate end which is long-term profitability. Likewise, Six Sigma will assert that all variability is “evil” and that it should always be as low as possible. History shows us that this is not always a good approach.

Compare the strategies of Henry Ford and Alfred P. Sloan. Ford produced a single model of automobile (Model T from 1908 to 1927) offered to the customer in “any color he wants so long as it is black.”[2] Ford was a fanatic about driving variability out of production. In 1921, GM had been a distant second to Ford with 12.3 percent of the market compared to Ford’s 55.7 percent. Sloan became president and CEO of GM in 1923 and set a goal to provide “a car for every purse and purpose” thereby greatly increasing the variability in the GM supply chain. But the strategy worked, and by 1929 GM had eclipsed Ford in the market, later becoming one of the largest corporations in the world.[3]

Unfortunately, the methods that enabled Sloan to create one of the world’s largest corporations sowed the seeds of its own destruction. GM’s centralized management and focus on finance made it appear profitable when it was not. Moreover, the strict requirement for a positive return on investment (ROI) prevented GM managers from seeing the need to implement changes that would be required to exist in a market that offered better cars for less money. In this case, the return on investment was necessary for survival. But after years of increasing profits and market share, hubris set in, and the question of survival was never raised.

Moreover, it is not because GM did not embrace Lean that it failed. Indeed, GM not only embraced Lean, but, in a somewhat ironic twist of fate, is listed as an example of “Lean Manufacturing and Environment” under the “Case Studies and Best Practices” website of the U.S. Environmental Protection Agency.[4] Nonetheless, on June 1, 2009, after almost 101 years, Alfred P. Sloan’s GM ceased to exist. GM declared bankruptcy, and all shareholders were essentially wiped out. The new GM was owned by creditors, the largest being the U.S. government. Today, the “new” GM is back on its feet after the U.S. Treasury sold its last remaining shares in December 2013. Whether it withers or flourishes will depend on how well its management understands the underlying principles of automobile production and marketing.

One problem facing the new GM and most managers in any large corporation is a constant need for action. This need breeds new “initiatives” whether they are appropriate or not and leads to a flurry of activity. The new activity often diverts attention from the fundamental problems rotting a company’s financial core. The Factory Physics approach avoids such activities by focusing only on those that are directly related to cash flow, customer service, and long-term profitability and by considering the tradeoffs among these.

Continuous improvement programs can be quite powerful, but simply having activities labeled as “continuous improvement” does not make a company successful. Next we consider one of the most successful (and long) continuous improvement programs in history—the Toyota production system. A scientific analysis of the Toyota production system provides a peek behind the curtains of folklore that have been laid over the secrets of Toyota’s success.

TOYOTA AND SCIENCE

Toyota is the archetype of Lean. In the 1960s and 1970s, Toyota was a car company that competed by producing inexpensive cars. However, quality was not a strong point. In a 2007 article in *Automotive News*, Max Jamiesson, a Toyota executive in the 1970s and 1980s, provided the following assessment:

> *“Back then, the car was a piece of junk.” When he left Ford Motor Co. for Toyota, his Detroit colleagues made jokes about Toyota being little more than recycled beer cans. They weren’t far from wrong, Jamiesson admits.*
>
> *He recalls that Toyota engines back then would “grenade” at 50,000 miles, and the brake pedal would “fold into the floor.” At high altitudes, Toyota carburetors needed to be propped open with Popsicle sticks, or the engine would starve from insufficient air-fuel delivery. But the exterior fit and finish was* [sic] *good.*
>
> *“The outside of the car was like a show car,” Jamiesson says. “All the lines and tolerances were perfect, so that when the salesman showed the car, it was beautiful. And the interiors were great, too. So we told Japan, ‘This is great; it shows we can make a quality car. Now make the rest of the car like that.’ The rest of the things need to function.”*[5]

From this inauspicious beginning, Toyota transformed itself into one of the most successful companies in the world and has offered one of the best-selling cars in

America, the Camry, for nearly three decades. Those of us old enough may remember the saying from that earlier time, “Cheap stuff … made in Japan.” Toyota played a huge role in changing that perception.

How Toyota Did It

So how did Toyota do it? One of the first things was to take a scientific approach and recognize that the manufacturing environment itself was not a static given but could be *changed*. Like Einstein, who rejected the notion of a fixed space and time, Taiichi Ohno and Shigeo Shingo rejected the notion that the mass-production practices of their day were the best practices possible. Instead of seeking to find the optimal lot size for a given setup time, they sought to reduce setup times until the optimal size was *one*! Indeed, “one-piece flow” became a hallmark of the Toyota Production System (TPS). This idea of focusing on the details of the environment was applied to such an extent that Toyota’s 5S process for making an operation clean and organized became an important part of TPS implementation. Toyota recognized that controlling work in process (WIP) with supermarkets (i.e., *kanbans*) and measuring output (i.e., *takt* time) worked better than trying to control output with a schedule and measuring WIP. Toyota also recognized the precedence of quality before production. An operator could stop the line if bad parts were being produced. “If you do not have time to do it right the first time, when will you find time to do it over” is a pithy aphorism that hits at the heart of this concept (and the basic concept of Six Sigma as well). Finally, Toyota empowered its employees to redesign workplaces over and over again until they found the most efficient configuration for the given task.

While these steps sound simple, and perhaps even obvious in hindsight, it is important to realize that while Toyota was perfecting its production system, equally “obvious” and *opposite* steps were being pursued in the United States. Ohno began developing Toyota’s system in the late 1940s and continued to perfect it into the 1970s. Thus, while Toyota considered *overproduction* to be a key waste, Detroit was happily pursuing mass production as the key to reducing costs. Long runs of millions of automobiles were produced by U.S. automakers in the belief that if the inventory did not sell when produced, it would eventually move when discounted at the end of the model year.

Given the results, it seems clear that although Ohno and Shingo never described the TPS in *scientific* terms, they understood the behavior of production systems at a very basic level. Shingo described practices in extremely poetic and flowery terms, for example, “The Toyota Production System wrings water out of towels that are already dry.”[6] This description is catchy but difficult to implement.

Many managers read about the almost miraculous results obtained by Toyota and are eager to put in a similar system and reap the rewards. They are often disappointed when they cannot achieve the same results in a few months. What they do not realize is that Toyota perfected its system over a period of more than 25 years. Of course, with the plethora of Lean literature available, one should expect results more quickly than that. Even so, it is likely that the journey will require a sojourn through the desert before reaching the Promised Land. For instance, if the production environment produces poor-quality products, the line will stop quite frequently as a manager begins to implement the TPS practice of stopping the line whenever there is a defect. This means that a defect that causes a problem for one station in a 10-station assembly line stops the *entire line* for some period of time. This can amount to a great deal of downtime.

Obviously, any lost time to address quality problems must be made up. One way Toyota did this was to schedule 10 hours' production into a 12-hour time slot. In this way, an extra 2 hours were available, if needed, for stopping the line, and yet the line could nearly always achieve its daily requirement needed to meet demand. Stopping the line was not costless. Toyota paid for its quality focus by paying for more capacity than it actually used. In contemporary parlance, this is called "undercapacity scheduling."[7]

While this sounds like a great deal of extra time, a 2-hour makeup period for a 10-station line absorbs relatively few stoppages. If each station had only one problem per hour and this problem could be remedied, on average, in 1 minute, the time lost on a 10-station line would be 2 hours for every 12 hours of production. This is exactly the makeup period that was described in Schonberger's best-seller of the 1980s, *World Class Manufacturing* (New York: Free Press, 1986). Producing for 10 out of every 12 hours yields a capacity utilization of 83 percent. If one line could not meet demand working 83 percent of the time, another line or overtime (with all the attendant expenses) would be required. But Toyota recognized that by allowing line stoppages for quality problems, the tension created would motivate people to eliminate the root causes of the line stoppages and thereby require fewer shutdowns and less makeup time. For a company just beginning its Lean journey, we would expect to see more issues per hour, and most would take more than 1 minute to resolve. Thus 2 out of every 12 hours represented world-class performance, which is why Schonberger reported it in his book.

The other hallmark of the Toyota Production System, one-piece flow, also comes with a cost. While one-piece flow results in minimum WIP and minimum cycle time for a given output rate set by the *takt* time, it requires additional makeup time. (We use the term *cycle time* to indicate the time required to produce a part from raw stock until completion. Other authors may use cycle time to indicate the process time on a machine. We prefer to call this *process time* and recognize that other authors may use such terms as *production time*, *throughput time*, *flow time*, and even *sojourn time* to mean what we are calling *cycle time*.) Indeed, if one watches an automotive assembly line operate for any length of time, one will typically see workers complete their tasks and have time to stand back and wait for the next vehicle. Unlike the two extra hours of makeup time used to accommodate line stoppages as a result of quality defects, these few seconds of makeup time are used to accommodate the variation in the task times.

For example, suppose that the demand for the Camry is 600,000 units per 250-day year. This translates to 2,400 units per day or 1,200 units per 12-hour shift. For a manager scheduling the line to work 10 hours each shift, the *takt* time will be 30 seconds ([10 h × 3,600 s/h]/1,200 = 30 s). This means that the time available at each workstation is 30 seconds. However, if the line's manager adds enough workers to the line so that the *average* task time is 30 seconds, there will be trouble. If the average task time is equal to the *takt* time, a station worker will be able to complete the task within *takt* only 50 percent of the time. This means that as the line continues moving, the worker will have to continue working into the next workstation, thereby disrupting that worker's work.

There are two ways to avoid such problems: (1) stop the line every time a worker faces a task that takes longer than the average or (2) set the *takt* time to be somewhat longer than the average task time. Thus, in the first case, the line will move at the pace of the slowest worker and will stop from time to time. However, if a manager uses the second option and sets the *takt* time to be somewhat longer than the average, some extra time is allowed for each station, thereby providing a very regular output for the entire line.

Now consider the histogram of task times in Figure 1-1 showing the distribution of times for tasks on an assembly line. About 5 percent of tasks take less than 20 seconds, 45 percent take from 20 to 25 seconds, another 45 percent take from 25 to 30 seconds, and the last 5 percent take more than 30 seconds. The average is 25 seconds, and the standard deviation is 3 seconds. Therefore, if the *takt* time of the line were set to 30 seconds, 95 percent of tasks would be completed in the time allotted. The workers should be able to deal with the 5 percent of occurrences that take longer than 30 seconds as long as they do not all happen at the same time.

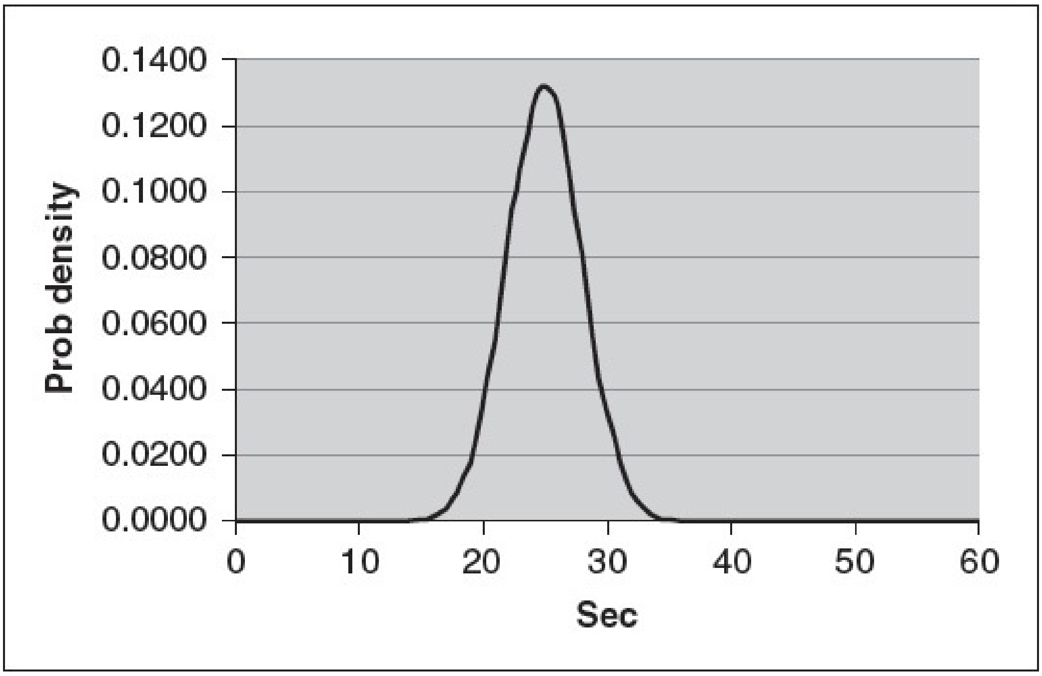

FIGURE 1-1. Histogram of task times

While 5 seconds does not sound like much, the extra time adds up. Moreover, performing a 25-second task in a 30-second *takt* time is equivalent to having an extra 2 hours available for each 10 hours of production because 25/30 = 10/12 = 83.3 percent. And since managers commonly employ the first method for long disruptions and the