Chapter Two

THE LEAN MANUFACTURING SYSTEM

THE SEARCH FOR PRODUCTIVITY IMPROVEMENTS AND THE GENESIS OF LEAN MANUFACTURING

Over the past 10 years or so, lean manufacturing has been receiving an increasing amount of attention as one source for productivity improvements and cost reductions in manufacturing. Hailed by its proponents as a breakthrough means to analyze and improve production and the factory floor environment, lean manufacturing is a broad collection of principles and practices that can improve corporate performance. The argument is that lean manufacturing offers revolutionary rather than evolutionary efficiency improvements. While lean manufacturing has received a lot of publicity since the term was coined as part of a study analyzing world automobile production, it is very difficult to find a concise definition of the term that describes all aspects of the system. Lean manufacturing is very closely related to Total Quality Management and derives from the Toyota production model. It involves a reconceptualization of the entire production process as a closely interconnected system from which buffers are removed. All the different activities that are part of the production process must be carefully coordinated to maximize the benefits of lean; the associated organizational and coordination requirements make implementing lean production a difficult and complex endeavor.

Liker and Wu (2000) define "lean" as "a philosophy of manufacturing that focuses on delivering the highest-quality product at the lowest cost and on time. It is a system of production that also takes a value stream focus. The 'value stream' consists of all the steps in the process needed to convert raw material into the product the customer desires."

Researchers at the Lean Aerospace Initiative (LAI) at the Massachusetts Institute of Technology describe lean as "adding value by eliminating waste, being responsive to change, focusing on quality, and enhancing the effectiveness of the workforce."[1] Babson (1995, p. 6) summarizes some aspects of a lean facility as follows:

> Inventories in a "lean" plant are taken on a just-in-time basis to minimize handling and expose defective parts before they accumulate in the warehouse; stockpiles of in-process work are also sharply reduced so that defects are immediately exposed at their source, before they fill the plant's repair bays with defective products; "indirect" labor (supervision, inspection, maintenance) is pared and specialized job classifications are reduced or eliminated, replaced by teams of cross-trained production workers who rotate jobs and take on responsibilities for quality control, repair, housekeeping, and preventive maintenance.

A systematic and continuing search for non-value-added activities and sources of waste forces a focus on quality and cost. New tools and techniques are incorporated as part of the continual effort to cut costs and improve quality and to enable reduced inventories and other lean practices.

Although lean manufacturing has its origins in the automobile-manufacturing sector, other industries have adopted the practices to improve their own operations. Womack and Jones (1996) offer several case studies of firms making radically different products, including stretch-wrapping machines, wire management systems and power protection devices, and aircraft engines, among others. Liker (1998) reports improvements for a tannery, a maker of sealing components, a scientific products company, a maker of outdoor cedar products (including birdhouses), a manufacturer of seismic exploration equipment, and companies in the automobile supply chain. Many other adoptions of lean principles have been reported as well,

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[1]http://lean.mit.edu/public/index.html. LAI is a consortium of industry, government, and academia dedicated to researching the benefits of lean production and propagating lean manufacturing throughout the defense aerospace industry.

although hard quantitative data on proven savings is unfortunately limited.

The search for improvements in production processes is by no means new. The eighteenth century economist Adam Smith is not usually thought of as an industrial engineer. However, his 1776 discussion in *An Inquiry into the Nature and Causes of the Wealth of Nations* regarding the division of labor in the manufacture of pins was one of the first formal examples of how to improve efficiency in production. Rather than having one worker make the pin from start to finish (drawing out the wire, straightening it, cutting it, sharpening it, putting the head on), he suggested that by dividing up the tasks involved in the production of pins and having a different worker perform each separate task, many more pins could be produced in a day. The process of dividing tasks into components and assigning different workers to complete each task was one of the enablers of the efficiency improvements in the industrial revolution, which was also driven by new sources of energy, new types of machine tools, population growth, broader changes in social structure, and many other factors.

The "father of scientific management," Frederick W. Taylor (1911) took a systematic approach to the organization of production. He focused on making workers' movements more efficient, giving them proper tools to do their jobs (e.g.., different shovels to handle different kinds of materials), and organizing work within the workspace to maximize the amount that could get done. Another critical aspect of Taylor's system was the sharp and stated distinction between brainpower of those managers best able to manage how the work actually gets done and the workers that do it. In essence, craft workers were to be "deskilled" (Braverman, 1974) and the analysis of educated engineer managers would replace worker specialist knowledge.

Henry Ford applied scientific management on a grand scale in the production of automobiles. The development of the movable assembly line, coupled with carefully machined interchangeable parts, brought the price of cars down from that of a rich person's toy to a tool for transportation that the middle and working classes could afford. The assembly line marked the transition from "craft" to "mass" production, which remained the dominant model through the 1980s.

Scientific management still drives managers today, as they search for the best way to organize work. Lean production follows this tradition of using careful analysis as a tool in productivity improvements. However, workers in lean factories are considered to be front-line experts on the manufacturing process who can and should participate in the continuing drive to improve productivity.

The improvements offered by Taylor, Ford, and many other thinkers sustained and enabled the growth of the U.S. manufacturing sector for many years and helped the U.S. economy become one of the strongest in the world. In the years after World War II, the United States was undeniably the most important industrial power in the world, with mass production its dominant model.

However, after other countries recovered from the ravages of war and successfully adopted new technologies into their industry, the United States faced more competition in world markets. For example, in the automobile industry, the 1970s and 1980s were marked by the decreasing dominance of U.S. auto manufacturers. Japanese cars became more and more popular, because of the powerful combination of high quality, low price, and better fuel efficiency. Also, Japanese manufacturers were able to take advantage of the oil crisis of the early 1970s by exporting to the United States the compact car models that were the standard in Japan. U.S. automakers were slower to respond with high-quality small cars of their own.

The crisis in U.S. auto manufacturing received increasing attention, as analysts proposed different reasons for the comparative advantage. One popular explanation was cultural, that the Japanese culture as expressed by the homogenous, hardworking people gave Japanese auto manufacturers an advantage based on a dedicated workforce willing to do things that American workers were not, such as going to unpaid meetings after hours to focus on efficiency improvements. Other analysts pointed to particular processes that saved costs, such as just-in-time (JIT) inventory delivery and statistical process control (SPC), which were pervasive in Japan but relatively rare in the United States. Still others pointed to the organization of the workforce, such as quality circles and flexible work categories, as the source of the Japanese advantage. However, U.S. companies adopting these techniques on an individual basis experienced mixed results. High-flying promises of new programs that failed to produce improved performance led to a kind of fatigue, where workers grew increasingly cynical about management commitment and the potential benefits of each successive effort.

In the late 1980s, the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (MIT) studied automobile manufacturers and compared the United States, Europe, and Japan, to learn the source of the Japanese advantage. The book that was published from this project, *The Machine that Changed the World*, (Womack, Jones, and Roos, 1990) introduced the term "lean manufacturing" to the United States. The authors argued that rather than one or another particular cultural factor, process improvement, or organizational technique being responsible for Japan's success, it was the manufacturing system as a whole. They found that a comprehensive system based on, among other things, maintaining minimal inventories and very high quality, was the basis for the success of the Japanese manufacturers, particularly Toyota. There are many overlaps with the total quality management (TQM) system, although the authors never mention this (Babson, 1995).

Although they popularized the term "lean" to describe the Toyota production system, the authors of the MIT study were not the first to introduce many of these ideas to the West. Indeed, a number of books written prior to the work of Womack and his associates addressed many of the same concepts. Ohno wrote *Toyota Production System: Beyond Large-Scale Production* in 1978 (translated to English in 1988), Shingo's *A Study of the Toyota Production System from an Industrial Engineering Viewpoint* was first translated into English in 1981, Monden wrote *Toyota Production System* in 1983, Goldratt and Cox published the first edition of *The Goal* in 1984, Schonberger penned *World Class Manufacturing* in 1986, and Suzaki wrote *The New Manufacturing Challenge* in 1987. However, *The Machine that Changed the World* was an enormously popular book with managers and was a tremendous sales document for the lean manufacturing system. A second book by two of the same authors, Womack and Jones, *Lean Thinking* (1996), has offered another take on lean manufacturing, and provides examples of companies[2] outside the automobile sector that had successfully adopted the system.

[2] Liker's (1998) edited volume offers further examples of lean producers.

OVERVIEW OF THE LEAN MANUFACTURING SYSTEM

Proponents of the lean system claim that it offers the potential for nothing less than revolutionary improvements in performance and cost. Womack et al. (1990) claim that with the entire system in place, production will involve "one-half the human effort in factory, one-half the manufacturing space, one-half the investment tools, one-half the engineering hours, one-half the time to develop new products." The authors also insist that unless the entire group of practices is adopted as a system, performance improvements will be negligible.

Japanese automobile manufacturers achieved high quality and low costs by removing buffers and impediments from the system, hence the term "lean." Eliminating excess inventory, for example, drives closer linkages between assemblers and suppliers, reshapes the factory floor, forces greater attention to first-time quality, and so on. Excess inventory means that manufacturing mistakes or broken equipment will not halt production because downstream processes can draw on inventories to keep going while the mistakes are remedied or the equipment is fixed. However, excess inventory costs money and can hide production problems that lead to greater problems later on. Mass production allows for excess inventory to provide a buffer against mistakes, while lean manufacturing aims to eliminate mistakes and hence the need for costly buffers. Removing inventory buffers requires very tightly coupled processes that closely link different functions within the organization. Further, Womack et al. have contended that the lean system must be adopted wholesale to see improvements. The synergies from applying lean to different areas of the manufacturing process are so significant that new processes cannot be properly understood alone or adopted singly. Such piecemeal efforts could only result in small improvements at best, a fraction of what full-scale implementation would offer.

The practices involve improvements on the manufacturing floor, in supplier management, in inventory management, in design and development, in human resources, and so forth. Attention to quality and flow drives costs down throughout the production process, from the design phase through final delivery to the customer. The authors of *The Machine that Changed the World* take a functional approach to lean processes in the plant and then make the connections across the different functions. In their construct, beginning in the design stage, products are developed to meet customer needs and to be easy to produce out of readily available components. This process requires the input of experts from all different areas on integrated product teams (IPTs).

On the factory floor, components of the product are manufactured one at a time ("single piece flow") in dedicated areas ("cells"). Attention is paid to decreasing setup times and improving first-time quality. Careful inventory management involving minimal or nonexistent inventory stocks keeps costs down, reduces required floor space, and drives the attention to first-time quality so that defects do not halt the flow of production. Similarly, close partnering relationships with suppliers contribute to lower costs and higher quality as suppliers deliver perfect parts and assemblies to the factory floor right before they are needed and continuously work to improve their own quality and reduce their costs. A trained and flexible workforce can play a role in continuous improvement and quality enhancement in a structure that allows workers to have jobs that are comparatively enriched. Close links with customers make sure their needs are met and final product delivery occurs when required. Overhead and other indirect costs are carefully managed as well, with attention paid to which procedures truly add value and which are not necessary (i.e., the collection of data for metrics that are never used), and levels of management structure are kept to a minimum.

In their second book on the topic, *Lean Thinking*, Womack and Jones (1996) depart from a specifically functional approach and offer a more general way of understanding lean manufacturing. They outline the five principles of the system as follows: (1) defining value for each product, (2) eliminating all unnecessary steps in every value stream, (3) making value flow, (4) knowing that the customer pulls all activity, and (5) pursuing perfection continuously. The five principles are laid out in some detail here because they contribute to the understanding of lean manufacturing throughout the plant. Taken together, these principles may offer powerful performance enhancements.

However, while companies can incorporate these principles in their business practices, they often do not correspond to the functional divisions within companies, which may be separately managed and about which data are separately collected. In addition, a practice that could help the plant get leaner as a whole may actually reduce the efficiency in one department. This point is relevant to defense production, where government regulations require the collection and reporting of costs in particular categories and where an increase in one category is not necessarily clearly linked to a decrease in another and so may look like inefficient cost growth rather than an expense related to overall performance improvement.

The first task in lean implementation is identifying what *value* the product has and what the value stream looks like. A fighter aircraft has value to its ultimate customer, the U.S. government (as a proxy for U.S. citizens) in its contribution to defense. The Joint Strike Fighter and F-22 Raptor offer different types of value to the government according to their different defense roles. Value is defined "in terms of specific products with specific capabilities offered at specific prices through a dialogue with specific customers" (Womack and Jones, 1996, p. 19).

Once value is specified, the next step is to determine the *value stream*. Manufacturers need to understand every step in the aircraft's construction, that is to say, the value stream, to produce it efficiently. Then, a manufacturer should continually look for unnecessary steps and other forms of waste (*muda* in Japanese) and reduce or eliminate this waste. For example, production engineers can measure distance traveled (either by the part or by the workers involved) in the creation of a part and search for ways to reduce it.

The third lean principle involves making value *flow* through the plant. Components of the final product should flow smoothly through the plant, going from station to station without a lot of waiting time in between. The traditional approach to this is manufacturing plants organized by task. For example, there would be dedicated cutting areas, dedicated drilling areas, and so forth. Parts would be brought to the area, stored until the machines were free, worked on, and then moved onto the area where the next process would take place. Management focus tended to be on the efficiency of the work station (for example in machine utilization rates) rather than product value flow. Another aspect of flow involves a continuing search for and analysis of bottlenecks in the production process. These occur when one operation slows the critical path of the product as it moves through the factory, thereby increasing total cycle time of production. This may be because of insufficient machine capacity, high tool changeover times, and so forth. As each bottleneck is solved, a new one is almost always identified, by definition, until the factory is completely "leaned" out. In the Toyota model, the process for identifying bottlenecks involves continuously speeding up the line and looking for points where the work is not getting done in the allotted time. Devoting resources to alleviate those stress points means the production line can run at a higher speed. The analysis of bottlenecks, while an important feature of the lean production system, is considerably more difficult outside the context of a traditional assembly line. Without a smooth yet rapid production flow, the bottlenecks may be invisible. Cellular layout of the plant, combined with a consistent, even production pacing, makes bottlenecks more obvious and allows their root causes to be identified and corrected.

The fourth principle is knowing that the customer *pulls* all activity. In short, this means that production should be tied to demand; no products should be built until downstream demand for them occurs. Pull production involves considerable collaboration with customers, to know what they require and when they require it, and with suppliers, to make sure their inputs are supplied at the appropriate time. Ironically, one of the strengths of the DoD and congressional budget processes is that they force conformance to this lean principle because defense manufacturers build aircraft only when ordered, after the money has been appropriated by Congress.

The constant pursuit of *perfection* is the fifth principle of lean thinking. Companies dedicated to lean manufacturing constantly search for ways to improve their efficiencies, to cut costs, and to improve the quality of their products. A number of tools can be drawn on. For example, *kaizen* events[3] are short (usually about a week) projects that study particular processes and look for low-cost ways for improvement. One example provided by Womack and Jones in *Lean Thinking* is of a series of *kaizen* events to improve the manufacture

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[3]These are also known as "action workouts." Technically, the term *kaizen* represents a broad approach that favors continuous improvement (Imai, 1986) but has been adopted in the United States as a descriptor for these short-term improvement exercises.

of vibration dampers at a Freudenberg-NOK factory in Indiana. Each event over a three-year period led to significant improvements. The question of why the company did not get it right the first time is misguided, since "perfection" must be striven for continually but can never really be reached, because further potential improvements in cost or quality always exist.

These five principles do not stand alone. Rather, there is considerable overlap in what they involve. For example, without near-perfect production, including very high-quality shipments received from suppliers, value cannot flow smoothly through the plant. Out-of-control processes will create problems. The search for waste and wasteful processes can help improve the quality of products and assist in the search for perfection, just as efforts toward continuous improvement will help identify waste. Both of these principles help the product (value) flow more smoothly through the plant.

As described, a major guiding principle of lean manufacturing is the removal of various forms of waste from the manufacturing process. For example, one major source of waste is the inefficient movement of parts throughout the factory. The entire time the part is in the plant, being moved from place to place and not being worked on, is classified as waste. Suzaki (1987, p. 12) reports seven types of waste identified at Toyota: waste from overproduction, waste of waiting time, transportation waste, processing waste, inventory waste, waste of motion, and waste from product defects. He adds an eighth type: the waste of underutilized people's skills and capabilities (p. 208). Implementation of lean manufacturing requires the identification and removal of these forms of waste but, more important, requires making the ongoing identification of this waste a critical activity. This underlies attempts at *continuous improvement.*

COMPLEXITIES AND CHALLENGES

Lean manufacturing is relatively easy to simplify, as it generally appears in most articles and books, including this one. In small plants, producing simple products, it may be easy to identify all the areas that must be changed to create a lean system. However, a single factory tour in a more complex industry, such as aircraft production, will make the analyst realize the challenges and complexities of any large-scale organizational changes, such as those presented by the implementation of lean manufacturing.

A related complexity arises from how lean principles cut across the whole enterprise but must be disaggregated and flowed down to different functional areas within organizations to get work done. Proper supplier management, inventory management, design and development, human resources,[4] and manufacturing operations are critical to lean production, but responsibility for managing these tasks are found in different departments throughout the firm. Implementing a truly lean system across a firm requires an intensive effort to tightly couple related tasks across functional departments. And lean implementation in different functional areas is closely related. For example, issues of concern during design and development can directly affect the manufacturing process, such as the ease of assembling parts into the final configuration. Just-in-time delivery requires the development of close ties with suppliers, keeps inventory low, and has significant effects on the factory floor. Truly lean manufacturing occurs when functions are tightly coupled across the organization to ensure that relevant issues for other functions are raised within each individual function.

Another set of complexities of lean manufacturing regards the cross-functional nature of many of the lean best practices in manufacturing plants.

These complexities make capturing cost improvements related to any one lean initiative or new lean best practice very difficult. Figure 2.1 shows the interrelationships of the various activities needed to manufacture a product and how all must be managed to improve overall operating efficiency.

It is not necessarily a given, in spite of what its proponents suggest, that lean production is the best way to do business. It offers a powerful package, but uncritically accepting all lean tenets, originally

[4]Note the enormous volume of academic literature on organizational theory that looks at the role and behavior of individuals in organizations. Scott's (1998) review of the organizational literature is an excellent resource for understanding these questions. Although some of this material is relevant to the discussions on lean manufacturing, providing a full accounting of it is beyond the scope of this document.

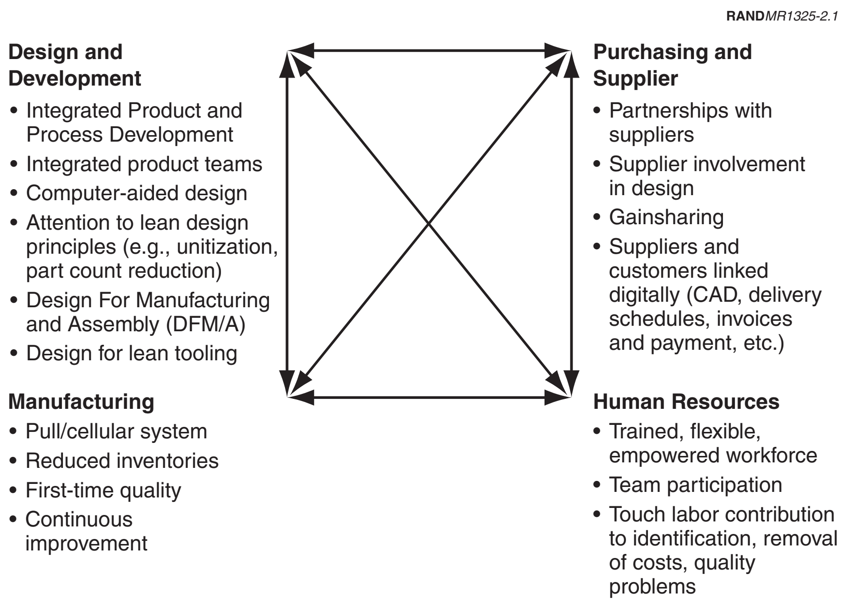

Figure 2.1—Lean Production Is an Enterprise Approach: Linked Functions Affect One Another

based on a high-volume industry, could lead to problems in low-volume situations. For example, aircraft manufacturing involves the production of relatively low volumes over a number of years. Some parts become obsolete and may be unavailable for the entire production run unless purchased at the beginning. This runs directly counter to JIT delivery of parts and is a particular danger in sectors characterized by rapid technological change, such as avionics. (However, Spear and Bowen [1999] report that at Toyota there is flexibility about the "no inventory" rule depending on circumstances.) Also, trade studies must be done to compare the costs of buying a couple of units a year with the costs of buying all required units up front when there are possibilities of volume discounts.

Another concern raised by researchers on human resources and industrial relations issues is the danger that lean production may be just another way to stress workers into producing "more with less," without giving them true input into how the work is done. Various critics have made similar points, including Rinehart, Huxley, and Robertson (1997); Berggren (1992); and several authors in Babson's (1995) edited volume. Proponents of the lean system counter that making workers work harder without giving them the means to work smarter is not truly lean and that lean production is impossible without an empowered and participating workforce.

Finally, no discussion of the possibility of efficiency improvements of 25 percent or more in an industry with limited competitive pressures would be complete without reference to Leibenstein's *X-Efficiency* (1966). Leibenstein argues that traditional measures of allocative inefficiency are inadequate to understand the scope of the costs of monopoly power. (While the defense aircraft industry does have more than one competitor and hence is not a monopoly in the fullest sense of the word, once a contract is awarded to a particular company, it becomes the only supplier of that aircraft and in that sense develops monopoly power.) In an extremely condensed form, the argument is that firms without competition lose incentives to search for normal operating efficiencies in their production and hence lag behind what the most competitive firms can do. They do not need to match the cost and quality improvements of competitors and so do not make the investments required to improve.

This behavior is fostered by the normal DoD contract negotiations for follow-on lots where price is a function of the costs of previous lots plus an allowance for profit. This raises the question of whether potential savings from lean production in the aircraft sector stem from truly innovative ways of doing business or merely from the adoption of evolutionary improvements that the firms just had not bothered to implement until pressured. Developing a thorough answer to this question is outside the scope of this report, however. The focus here is not to judge why opportunities for improvement exist but whether they exist, what savings are possible, and what goals are being achieved.

Lean Implementation in the Military Aircraft Industry

The potential for lean methods to improve efficiency, quality, and cost was not lost on USAF officials or the military aircraft industry. The LAI was born out of practicality and necessity as declining defense procurement budgets collided with military industrial over-capacity, prompting a demand for "cheaper, faster, and better" products. "The initiative was formally launched in 1993 when leaders from the U.S. Air Force, the Massachusetts Institute of Technology, labor unions, and defense aerospace businesses forged a trailblazing partnership to revolutionize the industry, reinvigorate the workplace, and reinvest in America using a philosophy called 'lean.'"[5]

Military aircraft companies have many features that distinguish them from nondefense firms in how they operate and manufacture products for their major and often only customer, the Department of Defense. These differences pose the question as to whether the same kinds of improvements experienced by commercially oriented firms can be implemented by DoD aircraft manufacturers. The first difference is the quantities produced each year. Even at its peak planned production, the JSF will roll off the line at a rate of just over 200 aircraft per year. In contrast, a single Toyota plant in Georgetown, Kentucky, has the capacity to produce 500,000 vehicles a year.[6] Secondly, commercial firms put their own funds at risk to develop and market a new product and either enjoy the profits to be made from a widely sold product or suffer the financial consequences for an unpopular product. In the military aircraft market, DoD pays for the development of the system and pays profit on the costs incurred during development. Although the companies' profit prospects are limited during production, their likelihood of loss is also practically nonexistent. Third, the approval process for a military aircraft development or production is complicated and time-consuming, with many participants involved in not only the initial acquisition decision but also subsequent funding decisions each year by military department and officials in the Office of the Secretary of Defense, as well as Congress. Thus, the ability to bring products to market quickly is hampered by the many government decision processes.

Finally, prices for military aircraft production are based on negotiated values, which are derived from assessing a manufacturer's costs

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[5]Lean Aerospace Initiative Web page (http://web.mit.edu/lean/).

[6]Toyota Web page (http://www.toyota.com/html/about/opertions/manufacturing/manu-locations/tmmk.html).

and allowing a reasonable profit as a percentage of those costs. This is where cost analysis has come into its own as an activity.

It became clear during the research for this report that defense firms tend to cut costs when competitive forces or pressures from their customers compel them to look for efficiencies. In the normal defense environment, with prices linked to costs incurred, the incentive to reduce costs to be able to enjoy higher profits does not exist as it does in a commercial market where price and cost are not as directly linked. Reduced costs in the DoD context can result in lower profits. Indeed, more than one company claimed that it was pressure from the JSF Program Office for the demonstration of real cost savings that provided the impetus to start efforts at improving efficiency by implementing lean manufacturing. The imposition of a cost cap by Congress on the F-22 provided a strong incentive to reduce and control expenses.

This points out the unmistakable distinction between current programs and potential programs, such as the JSF. Achieving cost reductions on an existing production program can be very difficult—a government agency may suffer as much or more from a canceled program as the defense contractor, so its power to exert pressure on costs through the threat of program cancellation may be limited. Without a tradition of reliable partnering with contractors in a joint effort to improve costs and profits, DoD lacks significant experience and resources to effectively encourage change on existing programs. In addition, once an aircraft design is agreed on, future changes, even for more affordable manufacturing, can require significant up-front investments that may not earn a return for several years and cannot be justified in a budget environment that discourages even multiyear commitments for major defense purchases. On future production programs, the government can threaten cancellation or competition if contractors do not keep their costs in line. However, once the procurement decision is made, cost-based contracts offer less incentive for contractors to pay close attention to costs, as long as program costs do not become high enough to jeopardize a weapon system's very existence.

The discussion of how to encourage contractors to adopt best practices grows out of historical evidence showing that effectively generating change is extremely difficult. Merely learning about the potential benefits of lean manufacturing through participation in a voluntary consortium, such as the Lean Aerospace Initiative, which disseminated lean lessons and techniques, proved to be insufficient to encourage companies to take the necessary but difficult steps toward broad organizational change. This frustration was expressed by Jacques Gansler, Under Secretary of Defense (Acquisition, Technology, and Logistics) when he said:

> I had hoped that, with five years of "lean" research under your belt, we would have begun to see some significant impact on the "top lines" of our defense programs, i.e., the overall costs and schedules for weapons systems. I am sure you agree that your successes in specific elements of the production process must be extended and accelerated to all our programs and—most important—that we begin to see quantifiable data demonstrating the benefits of the "lean" approach at the weapon system level. So far, we just haven't been able to produce such data. (Gansler, 1999.)

Complete implementation of the lean manufacturing system involves considerable organizational change. Aerospace manufacturers have shown that they can take the first steps, but they have not totally transformed themselves. Organizational change of any sort is a long and difficult process, and a transition to lean practices involves cultural and process transformations throughout the entire organization. Successful pilot projects limited to a few cells on the factory floor do not provide sufficient proof that this larger-scale change will occur.

Continuing interest, pressure, and/or incentives from the government for process improvements at manufacturers is required to keep their management focused on continuous improvement and could, over time, result in lower costs and higher-quality products. Without such actions by DoD, a very real danger exists that aerospace manufacturers will fail to take either the initial or follow-on actions required by the continuous process improvement focus of lean manufacturing. The next chapter will address how the military aircraft manufacturers have begun to implement lean principles in their companies.