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CAN LEAN MANUFACTURING CHANGE THE AEROSPACE DEFENSE INDUSTRY ?

by

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Lieutenant Colonel, USAF

A RESEARCH REPORT SUBMITTED TO THE FACULTY

IN

FULFILLMENT OF THE CURRICULUM

REQUIREMENT

Advisor: Doctor David G. Blair

MAXWELL AIR FORCE BASE, ALABAMA

April 1994

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ABSTRACT

TITLE: Can Lean Manufacturing Change the Aerospace Defense Industry?

AUTHOR: Cynthia L. Segersten, Lieutenant Colonel, USAF

In times of decreasing orders, increasing overhead costs and fewer customers, lean manufacturing techniques may allow the aerospace defense industry to remain healthy and profitable while offering the United States an avenue to maintain a more viable national industrial base. The automobile industry has shown lean manufacturing techniques can substantially reduce costs, cut development time, and produce a better product than mass production. The American aerospace defense industry is now working to implement these new techniques through the F-22 Engineering and Manufacturing Development Program, and the Lean Aircraft Initiative. European defense companies are also implementing the principles of lean manufacturing with results well worth noting.

BIOGRAPHICAL SKETCH

Lieutenant Colonel Cynthia L. Segersten (M. P. A., University of Southern California) became interested in the aerospace defense industry and how the Air Force acquires new aircraft while she was assigned to the Air Force Flight Test Center, a cornerstone of Air Force Materiel Command, at Edwards Air Force Base in 1986. The many fundamental problems of new aircraft, not discovered until late in flight test, suggested there must be a better way to design and produce new aircraft. As a native of Southern California and the daughter of an aerospace engineer, Lieutenant Colonel Segersten has grown up with an awareness of the problems plaguing United States' aerospace firms, which further sparked her interest in the subject. A supply officer, she has been assigned at every level from unit chief to commander of two supply squadrons. She has also completed tours at the Sacramento Air Logistics Center, and at Headquarters, United States Air Force Europe, where she headed the Command Equipment Management Team. In every case, she has been responsible for supporting aircraft after they became part of the Air Force's operational inventory.

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CHAPTER I

INTRODUCTION

In times of decreasing orders, increasing overhead costs and fewer customers, lean manufacturing techniques may allow the aerospace defense industry to remain healthy and profitable while offering the United States an avenue to maintain a more viable national industrial base. In the first section of this paper I will present and contrast the principles of mass production, originated and employed extensively in the United States during this century, and the principles of lean manufacturing developed and implemented in the Japanese automotive industry after World War Two.[1] Mass production principles were initially used to produce automobiles, although ultimately the methods extended the world over, and affected the processes used to manufacture millions of different items. The methodology of lean manufacturing differs significantly from that of mass production, and in the closing decades of the twentieth century lean manufacturing has produced dramatic successes in terms of volume, quality and customer satisfaction.

The lessons of the automobile industry have not been lost on aerospace defense companies that, because of massive cuts in the United States defense budget, are struggling in an intensely competitive market. The automobile industry has shown lean manufacturing techniques can substantially reduce costs, cut development time, and produce a better product that more precisely meets customer needs. Those companies that have successfully implemented lean production, primarily owned or managed by the Japanese, have done well in a very competitive market, while those that have retained traditional mass production methods have had a difficult time competing. Increased quality, flexibility, and affordability are potential benefits of lean manufacturing techniques that could have a vital impact on the aerospace defense industry. Yet, the aerospace defense industry is only now beginning to fully implement these new techniques. In the second section of this paper I will compare the automotive and aerospace defense industries, and analyze the applicability of lean manufacturing to aircraft production.

The benefits of lean manufacturing were first quantified in a study accomplished under the auspices of the International Motor Vehicle Program (IMVP),[2] as described in The Machine that Changed the World.[3] In an effort to use those lessons, the Aeronautical Systems Center (ASC) in Air Force Materiel Command is exploring ways to implement lean manufacturing in the aerospace defense industry as a way to obtain better weapon systems at lower costs. The first step is a study similar to IMVP called the Lean Aircraft Initiative (LAI). I will briefly describe the LAI, which will serve as an introduction to a leading-edge example of lean manufacturing in the aerospace defense industry today.

The F-22 Engineering and Manufacturing Development (EMD) Program will probably be the largest and most costly aircraft acquisition program of the decade. As a way to hold down program costs, government and contractor managers have structured the entire program around lean manufacturing principles. I will describe the F-22 lean manufacturing plan, explain how program managers will measure progress toward achieving true lean manufacturing, describe the successes already achieved early in EMD and some of the problems encountered, and finally I will project some of the difficulties the F-22 program may encounter in coming years.

The potential benefits of lean manufacturing have also been recognized by European defense companies who are now wrestling with many of the same problems, often to a much greater degree, faced by their American counterparts. In the final section of this paper I will describe European efforts to implement lean manufacturing, giving specific examples.

CHAPTER II

MASS PRODUCTION VERSUS LEAN MANUFACTURING

In the early 1900s, changes evolved in the United States that transformed the methods used to manufacture automobiles. The name that came to be associated with the new system was mass production. Ultimately, the effects of the new paradigm were so far reaching that they changed production processes all over the world, and affected almost every type of product it was possible to make using mass production techniques.[4] These world changing developments were based on the work and accomplishments of Henry Ford.

Initially, Ford was an automobile maker who created cars the same way every other car builder did in 1900. Sometimes called craft production, it was based on skilled craftsmen in small shops who built vehicles by hand, one at a time, to meet the particular requirements specified by each individual customer.[5] Design, engineering, component construction and assembly were accomplished for each car, and varied significantly from one car to the next. Skilled fitters were the crucial craftsmen who filed each part to fit with the part that preceded it in the assembly process. Volume was low, because the labor intensive building process was slow and expensive. No two cars were alike and parts were not interchangeable because craft techniques varied, and standardization was not a goal.

Ford was an innovator who proved the manufacturing process could be simplified, with far-reaching effects.[6] He made standardization his foremost goal, in order to make parts interchangeable between vehicles. To help achieve that, he introduced the concept of using a standard gauging system in the manufacture of every part. That eliminated the need to have every part filed or machined to fit together with adjacent parts, which in turn drastically reduced the requirement for the skilled fitters who were the bulk of the labor force in the custom car manufacturing business. The development of prehardened metals that were less apt to warp was an important advance that allowed Ford to reduce the number of parts needed, and to make parts easier to attach. Interchangeability, simplicity and ease of attachment were crucial advances that made the assembly line possible.[7]

Ford's assembly process evolved over a decade.[8] In 1903, it was based on an assembly stand where an entire car was built, sometimes by a single fitter. Later, an assembler would perform a large portion of the assembly, and then move to perform the same work on another car. By that point, Ford had multiple cars under construction at the same time, which represented a big change from the past. Only one model chassis that contained all the mechanical parts was produced which kept the process much simpler than it would have been if variations were allowed. Over time, Ford divided the labor into progressively smaller segments, and reduced the number of tasks a particular individual would perform. The Model T in 1908 was Ford's twentieth effort to design a car for manufacture. At that time an assembler would accomplish only one task per vehicle, before moving to the next. The task cycle was reduced to mere minutes, and the complexity of each task was low. Productivity increased because workers totally familiar with a single, simple task could perform it quickly and correctly. In 1913, Ford introduced the moving assembly line that conveyed cars past stationary workers. It reduced task cycle time even more, saved workers' walking time between cars, prevented congestion when faster workers overtook slower workers, and forced the slower workers to speed up to keep pace with the line.

The results were dramatic. A vastly greater volume of cars could be produced using less human effort. Therefore, the finished product cost less to build and could be profitably sold for a lower price, which in turn led to a much expanded market. "Ford dropped his prices steadily from the day the Model T was introduced."[9] Although not perpetual, it created a fortuitous cycle where "growing volume permitted lower costs that, in turn, generated higher volume."[10] "By the time Ford reached peak production volume of 2 million identical vehicles a year in the early 1920s, he had cut the real cost to the consumer by an additional two-thirds."[11]

Ford made the workers almost as interchangeable as the component parts.[12] Tasks were broken into simple components that made highly skilled laborers unnecessary. Training could be minimal, as were wages. This expanded the pool of available labor to include thousands of immigrants and the people moving from the farms into the cities. Laborers did not need to understand what they were doing, how their job related to the whole, or even the language of the other workers -- they simply had to accomplish their designated task in the time allowed.[13] The system did have drawbacks in terms of personnel. There tended to be a lot of turnover in the work force. Initiative was neither rewarded nor encouraged, and unskilled laborers had little expertise to draw on to detect or correct problems. Ford eventually raised wages to an unprecedented five dollars per day, so people stayed longer. But the working conditions were grim, and the work was repetitive and boring. Car companies treated the labor force as a variable cost, to adjust up or down based on product demand and profits. These conditions made the industry prime for a successful union movement. In the late 1930s, the United Auto Workers signed an agreement with what had become the Big Three.[14] Worth noting, the issues were shaped by the fact that the union movement accepted the role of management and the nature of the work as inherent to mass production in an assembly-line factory. Seniority became a key issue because it governed who was laid off when auto sales were down. Seniority also affected job assignments. Since wages were roughly equivalent, tasks that were regarded as easier or more interesting became the most sought after.

A side effect of this production system was the creation of a large array of specialists who were an integral part of the manufacturing process, yet never touched the product. These included numerous professional and managerial capacities, as well as a support staff.[15] Industrial engineers came into being to develop the assembly operation, the machines to make the parts, and the task breakout for the workers. Production engineers became responsible for providing parts to the line. Manufacturing engineers designed production machinery and tools. Product engineers designed the vehicles and their components. The need also existed for large numbers of narrowly skilled indirect workers including foremen, repairmen, quality inspectors, rework specialists and housekeeping personnel. Under craft production, all these functions were performed by craftsmen who required years of training and experience to develop their knowledge and skills. In contrast, Ford's system based on the division of labor, had masses of minimally skilled workers perform the manual labor, while a small number of experts directed the work. With some innovations as other firms entered the field, this was mass production in its mature form, and it dominated the automotive world market for decades.

In Japan after World War Two, another manufacturing paradigm developed. Initially called the Toyota Production System, or the Just-In-Time (JIT) production system,[16] it is now known as lean production (or lean manufacturing).[17] It began with the Toyota Motor Company that was founded in 1937 to build passenger cars. As early as 1929, Kiichiro Toyoda visited Ford's plant in Detroit. However, the war forced the company to make trucks for the military, with craft production used for the most part. After the war, auto production was resumed and Eiji Toyoda, nephew of Kiichero, visited the Rouge plant that was the largest and most efficient manufacturing facility in the world in 1950.[18] After examining Ford's system in progress, Eiji Toyoda and Taiichi Ohno, his production engineering expert, chose a different approach. Driven by widespread shortages in Japan after the war and a very different social structure than they saw in America, Toyoda and Ohno decided to combine the best features of craft production and mass production.[19] Containing elements of each system, they created a system vastly different from either. Extremely crucial is the interlocking way individual elements relate to each other to form the system as a whole. Begun in the 1950s, the system evolved to its present form. In many cases, past tense and present tense merge in describing development that has been ongoing for the last 40 years.

Human resources were very much the foundation of the new system. Workers were not considered easily replaceable, nor were they a variable to be laid off when profits dipped. Lean manufacturing works to avoid the "cyclicality" that is part of the Western idea of the business cycle.[20] Typically under mass production, "when the market goes down, the assembler companies jettison their human and organizational ballast and expect to find their workers and suppliers pretty much where they left them once conditions improve.[21] Under lean manufacturing, personnel were regarded as a long-term fixed cost. Hiring was from the bottom only, and lifetime employment was guaranteed. Pay depended on personal attributes such as academic accomplishments and years of experience,[22] and was tied to company profitability through bonus payments.[23] This generated two-way commitment. Employees had a vested interest in the company doing well, because their personal fortunes depended on that of the company. They also stood to gain little by switching from company to company because every move meant starting at the bottom again. At the same time, internal transfer of workers in response to company needs was easy because salary did not depend on the particular tasks being performed.[24] Since personnel were employees for multiple decades, the company was encouraged to provide necessary training for employees to become multi-functional workers who could handle various jobs.[25] The result was a much more flexible labor force.

Labor-management relations were simple. In Japan, only basic labor conditions such as salary, additional income based on company profits, and labor hours were subject to collective bargaining.[26] The manufacturing process (including machinery, materials, methods, and labor utilization) was not subject to discussion, which made implementing changes such as new technology, process changes, or productivity improvement much easier to accomplish.[27]

The nature of the work changed as well. Emphasis was placed on being a team member, with each individual a generalist "willing [and expected] to learn many skills and apply them in a team setting."[28] That fostered initiative and encouraged employees to anticipate problems and devise solutions.[29] The team leader was a working member who had the knowledge and ability to handle every operation, as well as to motivate the team. Working supervisors, and few supervisory levels were the rule[30] The number of specialties was greatly reduced, and many indirect worker positions were eliminated.[31] The goal was to have every worker actually add value to the car. All workers were expected to acquire additional skills such as simple machine repair, quality checking, housekeeping, and materials ordering.[32] Along with the wider variety of skills came greater responsibility. This is illustrated today by the fact that in Toyota plants, every worker has authority to stop the line if a problem arises that he cannot resolve. The new approach changed the job of every worker, and every manager, but it also created "more challenging and fulfilling work for employees at every level, from the factory to headquarters."[33]

Quality was another absolute priority. Lean manufacturing was based on the principle of systematically tracing every error back to its ultimate cause, and "then to devise a fix, so that it would never occur again."[34] Every employee bore the responsibility to detect, correct and prevent defects. The system also did not allow mistakes to build up, contrary to the "mass production practice of passing on errors to keep the line running [which] caused errors to multiply endlessly."[35] Nor were there intense inspections at the end of the production line to catch mistakes, so they could be fixed in a rework area. As Ohno's system developed, the amount of rework steadily decreased at the same time the quality of the completed automobiles consistently improved. Continuous improvement was a basic premise of the system. "Today, Toyota assembly plants have practically no rework areas and perform almost no rework. By contrast, . . . a number of current-day mass production plants devote 20 percent of plant area and 25 percent of their total hours of effort to fixing mistakes."[36] Key to the entire system is the fact that lean manufacturing builds quality control into every task, rather than trying to add it at the end of the process.

Flexible production methods were also a goal under the lean manufacturing system. Whereas mass production was based on producing gigantic quantities of identical items to realize economies of scale, lean manufacturing was deliberately designed to allow more options. Machines were engineered to allow simple, quick die changes-so they could be used to produce smaller batches of a variety of items. This permitted more models to be produced in the same time period, with little cost penalty.[37] It also made customization possible. Flexible methods dramatically reduced the amount of labor required to produce a car. Using contemporary figures to document the difference, the Toyota Takaoka Assembly Plant proved almost twice as productive as the General Motors Framingham Assembly Plant in performing the same set of standard activities on a standard car.[38] That was in addition to being three times as accurate. All represent advances accomplished under lean manufacturing that many people regard as revolutionary.[39]

Facilities were designed differently to facilitate lean manufacturing. The idea that "less is more" was built into the physical plant. There was less space between workers to encourage communication.[40] More compact work areas permitted no room for litter or discarded parts, for the simple reason that defective parts were immediately traced rather than simply discarded to litter the aisles. There was minimum area for rework, and inventory holding areas were small.

Inventory and suppliers were handled much differently under lean manufacturing. Large stocks of component parts were never accumulated. Instead the operative idea was to have small quantities manufactured and delivered as they are needed, hence the common term, "Just-In-Time" supply.[41] This often equated to having one or two hours of inventory on hand, versus months' worth. There were several significant advantages that prompted this course of action. Foremost was the quality issue. With small amounts produced <u>and</u> used soon after, it was possible to readily detect defects before many problem units were produced, or they could be built into completed automobiles. Facilities could be smaller because less space was needed for storage. Excess was not a problem when models were changed and less capital was tied up in inventory. Steady consumption also helped eliminate the cycles so prevalent in mass production systems. Suppliers could produce and deliver at a steady rate, rather than working overtime to fill a large order, and then setting idle until the next order. Also, large quantities were not purchased and held as a hedge against possible price increases which further aggravates the cyclicality often experienced under mass production.

Just-In-Time supply does incur risk for the manufacturer, should a supplier fail to produce or deliver in time, or if there is a quality problem. Lean manufacturers minimize that by cultivating close ties with their best suppliers. Suppliers whose performance merits such respect based on their ability to provide high quality, low cost and short delivery time, can in turn depend on long-term customers for continued business. "Nearly 38 percent of all Japanese subcontractors make 75 percent of their total sales to one paternal company. In total, 63 percent of the subcontracted companies rely on their primary paternal company for more than 50 percent of their total sales."[42] Mass producers often pit suppliers against each other, expecting to obtain better prices out of the competition. However, that creates adversarial, short-term relationships, which are not very reliable in terms of price or quality, which means the manufacturer must maintain relationships with many suppliers.[43] It also hinders the exchange of information between manufacturer and suppliers. Lean manufacturers try to work with their suppliers to jointly design parts, thereby reducing costs and improving quality. Assemblers strive to capitalize on suppliers' manufacturing experience and expertise, because that saves the assembler having the cultivate that knowledge.[44] Lean manufacturers often offer incentives to suppliers, or help finance improvements.[45] They may own a portion of their suppliers' stock, and the various component suppliers may have "substantial cross-holdings in each other."[46] At the same time, suppliers have equity in the assembler's company, and there is sometimes a cross-flow of personnel. Each of the companies is independent, but they share destinies, which encourages each to look after the best interests of the others.

Like suppliers, customers are also treated much better under the lean manufacturing paradigm. Knowledge of their particular needs and desires is sought, and seriously heeded during the production development process. Sales are much more personalized. Lean manufacturers strive to foster such total brand loyalty that their customers buy only one brand for life.[47]

The final key component of lean manufacturing is lean design of future products to perpetuate the process. Predictably, many of the principles of lean manufacturing are applied to lean product development. Central to any effort is a project development team.[48] Teamwork and shared expertise are emphasized, rather than the narrowly defined specialists characteristic of the mass production system. Team members representing all relevant expertise are assigned to the team for the life of the project. Leadership is crucial. Team leader is a strong position, not just a coordinator of experts who report to other functional departments. Communication is optimized. A project involves the greatest number of people as it starts, so conflicts and tradeoffs can be decided early, under controlled circumstances, rather than as a compromise at the end to resolve a total work stoppage. Simultaneous development of dies and body design is used to save time, based on the premise that people can work together well enough to avoid serious problems. "Ease of manufacture" is emphasized throughout the design process[49] which ultimately reduces the amount of effort as well as the time involved to manufacture the finished product.[50] Certainly results vary between companies and projects. However, a recent study comparing Japanese lean design efforts to American and European mass production projects showed nearly a two-to-one difference in engineering effort and a saving of one-third in development time.[31] Such a magnitude of difference has to be regarded as a strong indorsement for the results possible using lean manufacturing and design techniques.

The effects of lean manufacturing are evident in our everyday life. Japanese cars, manufactured using lean production techniques, are designed and produced much quicker than mass produced cars, at a lower cost, yet consistently are rated as the highest quality cars in the world. If the aerospace defense industry could successfully apply these techniques, the companies would be better able to cope with the smaller orders that are the norm today while still maintaining profitability.

CHAPTER III

LEAN MANUFACTURING AND THE AEROSPACE DEFENSE INDUSTRY

Before looking directly at the applicability of lean manufacturing, it is interesting to compare the present environment that exists for the United States automobile industry, which is still largely traditional mass producers, with the aerospace defense industry. Both products, aircraft and automobiles, are becoming more expensive to produce, more technologically advanced, and increasingly complex to manufacture. At the same time these products cost more, customers believe they can afford to pay less. In the case of defense aircraft, the perception of a reduced threat and the end of the cold war is resulting in greatly decreased defense budgets. The United States Congress wants to divert defense dollars to increase trade, strengthen the economy, decrease the national deficit, lower taxes, expand welfare programs and health care, upgrade infrastructure, improve education and environmental protection -- to name a few of the competing priorities. Both industries also find themselves in somewhat of a crisis; the automobile manufactures facing intense competition from the lean producers and a flat market, and the aerospace defense industry from an unexpected and enormous downturn in government orders. The United States automobile industry has responded by moving rapidly toward lean production. The aerospace industry has laid off thousands of workers, much in the tradition of mass producers, but has otherwise yet to respond effectively to the crisis and is still searching for solutions.

Comparing the processes of the traditional mass production automotive industry and aerospace defense industries indicates an overwhelming number of similarities which strongly suggest that lean manufacturing techniques and procedures which have already demonstrated improved quality, increased flexibility and reduced costs in the automotive industry, could be a source of similar benefits if implemented in the aerospace defense industry. Both employ highly trained engineers, traditionally organized along functional lines such as landing gear or hydraulic systems in an aerospace defense company (or brakes and drivetrain in the automobile industry), who are responsible for the design in their particular specialty. After the design goes through a critical design review, the drawings are turned over to the manufacturing engineers who design the tooling and processes for assembly. Finally, semiskilled workers follow the processes and drawings produced by the engineers to produce the product. Throughout this very sequential design effort the engineers are responsible to their functional boss, not the product leader responsible for the project. Manufacturing problems are not addressed until very late in the design process, when changes are most expensive and difficult to make. While the increased complexity of the subsystems manufactured by aerospace subcontractors has fostered closer ties with aerospace companies than has traditionally been the case with the mass producers in the automobile industry. the relationship falls far short of that enjoyed by lean producers. The major aerospace companies usually rely on interface control documents and system specifications in dealing with the subcontractor instead of the build-to-print drawings used by mass producers, but still have no insight into the subcontractor's processes. Because of the additional cost, the major airframer does not usually bring the subcontractors onboard early in the design process to gain their expertise in setting specifications. Thus, they leave open the possibility of specifying an expensive design when a cheaper, simpler and more reliable one may have been possible by reducing requirements just a few percent, or by shifting a particular function to another subsystem.

The successes of lean manufacturers in overcoming the challenges described above suggest the same principles could well be applied to aerospace defense companies. By reorganizing along product lines instead of functional lines, manufacturing concerns could be addressed early, leading to a more producable design. Integrating design engineers with production technicians all concentrating on ease of manufacturing as well as performance would certainly lead to weapon systems that are easier to produce and repair. Engineers, with a single boss, would be better able to focus on solving problems early in the process, instead of delaying until they have grown enough to attract management attention. Perhaps the most dramatic savings are possible in shortened development times. One of the largest drivers in the high cost of weapon systems is the long product cycle. Today it is sometimes 15 years between concept development and when the weapon system is fully fielded. Such a long time forces companies to keep thousands of workers on a project for many years while at the same time the government is forced to implement numerous and expensive design changes as requirements change and new technology becomes available. Shorter product development cycles, such as those the lean manufacturers have already demonstrated relative to traditional mass producers, could slash costs dramatically while providing the customer a more state-of-the-art system that better meets requirements. If the one-third decrease in development cycles seen by lean producers could be repeated by aerospace manufacturers, the cost savings would be billions of dollars.

Changing the role of the subcontractors and major suppliers should yield the same results in aerospace companies as in lean manufacturing automobile companies. By incorporating concerns of the subcontractors early in the design process, the major airframers will not only have better defined specifications and interface control documents, but when changes are required they will have a much better understanding of their cost, schedule, and performance impact. This in turn will lead to a less expensive and higher quality product. Just-In-Time delivery techniques, impossible with traditional supplier relationships, could be implemented if subcontractors and airframers work more closely together, further cutting costs by reducing expensive inventory.

Key differences also exist between the automotive and aerospace defense industries. Aircraft are a great deal more complex and expensive to develop, produce, and purchase than automobiles. Instead of production runs numbering in the hundreds of thousands, future aerospace orders will probably be just a few hundred at most. Finally, workers on the manufacturing floor in the aerospace industry are more highly skilled than those in the typical mass production plant. However, rather than calling into question the applicability of lean manufacturing, it can be argued that these differences should be viewed as incentives. The complexity of an aircraft as compared to an automobile is one of magnitude, not kind. Both are powered by advanced engines that must deal with concerns of fuel economy, low maintenance, low weight, and environmental impact (emissions for automobiles and smoke for aircraft) that force compromises in the design. While function initially drives the overall shape, the design of automobiles and aircraft must be tempered by aerodynamic concerns as well as inputs from other areas (styling for automobiles and radar cross section for modern fighters). It is very probable that application of an integrated product approach and lean manufacturing techniques instead of the more traditional stovepipe functional lines will yield even greater benefits in a complex system such as aircraft. One of the most positive results of lean manufacturing is that parts and systems work together better than those designed and made using traditional methods. Complex mechanisms with many interactions suffer greatly when one particular part or system fails to meet specification or performs poorly. An engineering change in a single component, can have far-reaching effects on subsystems that are often manufactured by outside suppliers As the redesign effort trickles throughout the weapon system, cost increases exponentially and the schedule slips ever further behind. So it would seem that complex systems are even less tolerant of the inefficiencies inherent in mass production than simpler machines such as automobiles. Also, the advanced metals found in aircraft are expensive and sometimes impossible to rework, suggesting that the more efficient manufacturing methods resulting from lean techniques may result in dramatic cost savings.

The smaller production runs expected in the future are a strong argument against traditional mass production techniques. Downsized drastically from past decades, current contracts are for very small quantities of aircraft, such as only 20 B-2s. Instead of the thousands of F-16s produced in the 1980s, the total buy of F-22s will probably be less than 500 (the current buy stands at 442). In today's environment, companies using mass production techniques and configured on functional lines are doomed to fail because they depend on large production runs to attain the economics of scale that allow that system to operate. Mass production, dependent on very large numbers of identical units, is poorly suited to the smaller numbers found in aerospace companies. Lean production on the other hand, with its emphasis on flexible tooling and more rapid innovation on the manufacturing floor by the workers, is much better suited to the aerospace industry. The emphasis on machines that can accomplish multiple functions makes sense in terms of not tying up resources or facility space with overly specialized equipment that will be used to make only a few hundred items, not hundreds of thousands.

Ironically, today's aerospace defense industry has elements of craft production, employing more highly skilled assembly workers than the automobile industry. Craft production might at first glance seem better suited for the smaller production runs foreseen in the future. Unfortunately, standardization requirements and the complex technology of modern aircraft prevent a return to the days of true craft production when each item was hand crafted on an individual basis. However, the better trained work force already in place bodes well for implementation of lean production techniques. The more highly educated aerospace worker, who already enjoys a better understanding of manufacturing techniques than his automobile industry counterpart, will become even more productive when empowered to make continuous improvements as demanded by lean production.

Perhaps the biggest impediment to implementing lean production in the aerospace defense industry is the fact the companies have never had to truly compete in a free market, and therefore have less incentive to be "lean." More than any other factor, this may explain why defense companies have lagged behind other manufacturing segments in implementing lean manufacturing techniques. If costs rise during the acquisition cycle, companies have traditionally enjoyed great success in obtaining more money from the government to cover what would be huge losses for a free market company. After having experimented with various types of contracts during the past decades, it is still not clear the Department of Defense has found a way to successfully share the enormous risks associated with weapon system development with the companies. Therefore, aerospace defense companies may lack sufficient economic incentive to make the fundamental organizational changes needed to implement lean production.

While government contracts may not offer the economic incentive to change, the post-Cold War defense market just might. Historically, the Department of Defense has always had enough business to keep all the aerospace defense companies profitably employed. New aircraft orders, typically several each decade, for thousands of aircraft were usually spread among numerous companies to keep the defense industrial base strong. As pointed out earlier, this is no longer the case. New aircraft buys are now much smaller, and it appears Congress may allow only one new aircraft into production each decade. Much like the Big Three in the 1980s, the aerospace market has gone from plenty for everyone to being very competitive.

The rapidly shrinking market has already had an effect. The aerospace defense industry is now down to only four major airframers and two engine manufacturers, as market conditions have forced mergers and outright withdrawal from the market. Such large and well-known companies as Grumman and Rockwell are no longer major players in the airframe business. In discussing his company's withdrawal as a major airframer, Grumman Corporation Chairman and Chief Executive Officer explained, "We were shown a chart [from Secretary of Defense Les Aspin's Bottom-Up Review] indicating the number of fighter aircraft primes in the business now and the number that will survive by the end of the decade. The number was two. It's obvious Lockheed and McDonnell Douglas are the odds-on favorites. They have the resources to ride it out. We don't. The Defense department was pretty clear: There's no room for us -- or for many of our competitors -- in the airframe business."[52] Even so, the economic health of the remaining companies is not assured. Following the award of the F-22 Engineering and Manufacturing Development contract to Lockheed and Pratt and Whitney in 1991, the losers in the competition, Northrop, McDonnell Douglas, and General Electric, laid off thousands of workers and saw their stock prices tumble. Thus, the incentive to implement lean manufacturing is the fact that for the first time aerospace defense companies are vying for business in a very competitive market.

CHAPTER IV

THE LEAN AIRCRAFT INITIATIVE

The aircraft industry suffers many of the problems found in the automotive industry, including rapidly declining market share, over capacity in capital and labor as well as lengthening design times. On the basis of IMVP conclusions, and benefits since derived by American companies that have adopted lean principles, the ASC Commander, Lieutenant General Thomas R. Ferguson, Jr. (now retired), directed an evaluation of the application of lean production to the aircraft industry in May 1992.[53] In November 1993, direction was given to proceed with an IMVP-like program for the aircraft industry. Titled the Lean Aircraft Initiative (LAI), it represents a consortium of industry, government and academia. National labor union officials are also involved in the effort.[54] Sponsored by 25 companies[55] and the Air Force, it will involve a three-year research effort based at the Massachusetts Institute of Technology (MIT).[56] The study is expected to cost an estimated $5 million, which will be shared equally by the Air Force and industry. Using lean production principles as a starting point, it will make a comprehensive examination of all sectors of the aircraft industry -- including airframes, engines, avionics, equipment, subsystems, and government-industry interfaces. Specific focus areas that have been identified are: product design and development, fabrication and assembly operations, supplier networks and relationships, organization and human resources, policy and external environment.[57]

The intent is to identify lean production techniques that will let the aerospace industry develop higher quality products in less time at lower costs. Specific goals include shorter design time, smaller inventories, fewer management layers, less capital outlay, less cycle time and fewer suppliers.[58] The study is also expected to "provide hard data that could be useful in reforming the acquisition process, specifically identifying government regulations and procedures that impair efficiency."[59] and "government accounting, oversight and contract practices that do not add value to a product."[60] An educational program at MIT dealing with systems engineering and manufacturing technology is being developed in conjunction with the LAI.[61] Professor Daniel Roos, Director of

MIT's Center for Technology, Policy and Industrial Development, was a key researcher in the IMVP presented in The Machine that Changed the World. He will also be one of the LAI project directors. He reports he has been impressed by the response from the industry during nine months of preliminary research.[62] "He expected companies to be reluctant to discuss what they considered proprietary information . . . [but] faced with the prospect of a shrinking defense budget, fewer new program starts and smaller production runs, industry officials realize that dramatic changes are needed."[63] The LAI officially began its assessment and implementation phase at MIT in May 1993.[64] By the end of June 1993, seven research projects covering the various focus areas were underway or in advanced planning.[65] While some preliminary findings have been presented from the LAI pilot research project on inventory practices,[66] it is too early to draw firm conclusions from the LAI effort. However, indications are the potential exists to realize benefits similar to the improvements made in the automobile industry as the result of the IMVP study.[67]

CHAPTER V

LEAN MANUFACTURING IN THE F-22 PROGRAM

Lean manufacturing techniques are already being employed as an integral part of the F-22 EMD Program, involving the government acquisition team and the three companies who comprise the prime contractors responsible for building the weapon system. The overall lean manufacturing plan is described in the F-22 Lean Enterprise General Plan, which focuses on two key concepts: "(1) optimization of the major enterprise process flows and (2) driving out waste in all forms from these process flows."[68] This top level document details how each of the three companies, Lockheed Aeronautical Systems Company (LASC) and Lockheed Fort Worth Company (LFWC),[69] Pratt and Whitney, and Boeing Military Aircraft (BMA) will implement lean manufacturing. While differing slightly in details based on how each company operates, all documents are similar in concept and scope. In this paper I will discuss only the LASC plan, as it is representative of each of the lean enterprise company plans.[70]

The LASC F-22 Lean Enterprise Company Plan is divided into five areas: design, factory operations, supplier chain, customer relations, and management. Within LASC and between the major partners, integrated product teams (IPTs) have been established for every major design activity of the F-22, along with a tiered integration/review process of selected senior functional representatives. This scheme is virtually identical to the management structure used by successful lean manufacturers in other industries. One added nuance that has not been necessary in the automobile industry is the addition of government engineers and program managers as integral members of the IPT process. For each IPT in the company, there is a corresponding IPT in the government. The company IPT leaders and their government counterparts are expected to function together as members of a unified team, rather than in the adversarial roles that have typically characterized past weapon system acquisition programs. This structure should reduce the total number of expensive and time-consuming design changes that typically occur throughout the program. Therefore, LASC is using the number of cumulative engineering design changes per released drawing as compared to IPT-developed goals as the metric for successful implementation of lean manufacturing in this area.

Factory Operations is an area where LASC hopes to reap significant benefits. The Factory Operations portion of the F-22 Lean Enterprise Company Plan centers on a new organizational structure aligned to major process flows. In Fabrication and Assembly, these new organizational structures are called focused factories. Each focused factory is related to a major group technology product family (in this case the F-22) and all the resources required to achieve the product family output are contained within the focused factory. Management is arranged so one manager has complete control of the process under his or her authority. In Production Engineering, pilot programs using artificial intelligence algorithms are being evaluated to reduce throughput time and cost in tool design and parts programming. In Materiel, LASC is in the process of reducing new material inventory from seven months to three months' worth of inventory on hand, and progressing from there to daily delivery. To measure the effectiveness of these plans, LASC is using four metrics: (1) cost of scrap, rework and repair or defects per million by time period, (2) process capability baselines for processes that control key characteristics of critical parts and assemblies, (3) inventory turns, and (4) reduction of fabrication and assembly Quality Assurance inspections.

The major effort to integrate lean manufacturing practices into the supplier chain is to bring suppliers into the IPT environment. LASC has initiated a supplier rating system by which each vendor is rated on a regular basis. This information is shared with the vendor so management attention can be focused on those areas needing improvement. Two metrics are being used to measure supplier compliance with lean manufacturing objectives: (1) reduction of incoming inspections based on supplier-demonstrated capability, and (2) the percentage of key vendors who agree to pursue lean enterprise objectives.

A more focused approach to customer needs is evidenced in the government-contractor IPT structure which it is hoped will lead to closer working relationships. Integrated team activities are used instead of metrics as a measure of the effectiveness of better communication with the customer. Examples include annual Senior Executive Off-site Conferences and periodic program reviews.

To improve the efficiency of the management process, LASC is creating new organizations to better align management responsibility with the key manufacturing processes. The focused factories discussed previously are an example of this approach. The metrics used to measure this area are conformance to standard Cost/Schedule Control System Criteria (CSCSC) data and the Integrated Master Plan and Integrated Master Schedule.

The adoption of lean manufacturing principles has already led to dramatic improvements. In the Fabrication shops, a pilot project was established to validate the focused factory concept that has been running successfully for over two years. Inventory, as measured by shop orders in-process, dropped from a high of 6,000 (and a low of 600) to just 500, and throughput measured in days dropped from 65 to 15. This suggests the focused factory concept shows great promise as the program moves from design to assembly. Customer relations between the contractors and government engineers and managers have reached positive levels never seen just a few years ago, suggesting a new paradigm has indeed taken root. Contractor and government IPT leaders have adopted an attitude of sharing problems and responsibility, while working together to find solutions. In other programs, such a close working relationship would result in accusations of "being in bed with the contractor." In fact, government managers now become aware of problems earlier when they are better able to help, and contractor engineers get fast answers to requirement questions, allowing them to provide exactly what is needed and nothing more. "Gold plating" a design to meet some obscure contractual requirement that the customer does not consider crucial, should be a thing of the past.

As with all new ideas, growing pains have occurred and some unforeseen problems have materialized. While the IPT structure has many benefits, one drawback is the tendency for IPTs to become too focused on their individual product, sometimes forgetting their larger purpose to produce a weapon system. LASC has responded by creating Analysis and Integration (A&I) Teams at several levels to pull together the designs of the various IPTs. A good example of the value of the A&I Teams was the summer 1993 discovery that the baseline design did not correctly integrate the complex, interdependent aircraft subsystems to allow all to be brought on line during normal engine start. The team also focused on improving cockpit starting procedures, as the basel[illegible] required constant pilot attention and action, causing a high workload. The IPTs, together with the A&I Teams, have now produced a user friendly design that has been highly praised by Air Combat Command pilots.

Another area of concern is the personnel system presently in place at LASC. Unfortunately, the IPT structure is not recognized by the Human Resources Group that manages personnel actions, performance appraisals, and ultimately, pay. This has led to contradictions such as IPT leaders not being recognized as managers and therefore not receiving the benefits to which someone in their position is normally entitled. At the same time, an IPT leader may have a subordinate several levels down receiving higher pay and other perquisites because he is considered a manager under the "old" system (as recognized by the Human Resources Group). Further compounding the problem, IPT leader appraisals are written by the functional supervisors recognized by the Human Resources Group, rather than by the IPT leaders at the next higher level. Such inequities understandably lead to friction and other problems. A specific example of such problems arose in early 1994 when a Lockheed IPT leader tendered his resignation. Despite his 50-60 hour work weeks and intense responsibility, he had people assigned to him who were working a standard 40 hours per week, being paid several thousand dollars more per yea. and receiving higher appraisals. Finally, he decided to return to being one of the 40-hour-per-week workers, and let someone else deal with the stress, worry and time consuming responsibilities. Unfortunately, this is not an isolated instance. To realize the benefits of lean manufacturing, there must be changes in personnel management so the system can operate as intended.

Finally, as in any new paradigm, change is sometimes difficult. There are still those within contractor and government management who do not fully support the new relationship the IPT structure has fostered, and are uncomfortable with the openness required.

The F-22 program has adopted many of the tenets of lean manufacturing, yet the final verdict is far from in, and the overall outcome will not be known for many years. Many questions remain to be answered. For example, the government-contractor IPT structure has not yet been tested under fire. Until the recent budgeting rephase effort described later in this paper, the F-22 was always the protected child of the Air Force and received the funding requested. Now, with some government officials questioning even the need for the F-22, that is no longer the case. The program can expect rough times ahead that will try the close relationships developed in better times. It must be remembered the government and the contractors have fundamentally different purposes. The F-22 government program managers are responsible for procuring a weapon system that meets the Air Combat

Command requirements at minimum cost, while the contractor managers must answer to stockholders and show a profit. The cost plus award fee contract helps merge these differing goals, but when there is simply not enough money to go around, the government managers will inevitably pressure the contractor teams to do more with less. The rephasing effort led to a few strained relationships, but this could be just the first shot in a very long budget war.

Perhaps the biggest impediment to successful implementation of lean manufacturing in the F-22 is the environment in which development is taking place. To a degree not found in the automobile industry, the acquisition system is susceptible to outside budgetary and political influence that could seriously interfere with the promised efficiencies of lean manufacturing. No bank would suddenly cut funding it had promised on a new car development part way through the design, yet that is exactly what happens routinely in government acquisition. Year to year funding over the design cycle is far from certain, and while many other aspects of the F-22 program have changed as a result of lean manufacturing initiatives, sometimes dramatically, the political and fiscal structure remains much the same. Requirements changes are sometimes mandated from the United States Congress, not the customer, which result in costly and time consuming changes to the aircraft. In addition to dealing with the uneven funding that can result when national priorities change, the F-22 program managers are constantly asked to justify every requirement of the program to politicians who often do not have the technical background to understand why decisions are made as they are.

The uncertain funding has already had a dramatic impact on the F-22. In May 1993, the F-22 Program Manager was told that the FY 1994 budget would have to be reduced by $283 million. It took nearly six months of intense effort, called rephasing, by government and contractor personnel to restructure the program budget to meet the new yearly funding ceilings.[71] They achieved this by sliding major events and schedule milestones to the right and cutting back on the scope of the EMD effort. For example, the critical design review for the air vehicle was delayed five months and first flight was slipped nearly a year to mid-1996. The number of EMD test aircraft procured was reduced from 11 to 9. Not surprisingly, total program costs increased $714 million.

While it is difficult to precisely analyze the effects this will have on the efficiencies resulting from the implementation of lean manufacturing methods, some adverse impacts are inevitable. The success of lean manufacturing depends on reducing all schedule and process inefficiencies to zero by having the correct number of personnel working on the right tasks at just the right time. Subcontractors and vendors must deliver parts and subsystems just when they are needed. While the rephasing effort succeeded in reducing the budget to match the funds allocated by Congress, the numerous changes in the schedule wrought havoc on months and years of efforts to optimize deliveries by subcontractors, and the manpower allocated for the various efforts. LASC, LFWC, and BMA have precisely calculated the number of engineering and factory workers needed throughout the lifetime of the contract. With the introduction of schedule slips, it is inevitable that at some times the workers will not be needed because the task they were supposed to be working on has slipped. In fact, in computing the additional costs as a result of the program delays, government and contractor financial experts typically use a 20 percent reduction in efficiency for the amount of time equal to the slip, in this case eight months. Similar manning problems afflict the subcontractors. For example, once LASC puts a subcontractor on contract to deliver a given component, that subcontractor in turn begins hiring the necessary manpower and technical expertise, and sending out requests for proposals to his vendors for the raw materiel that will be needed to begin production. The introduction of a six-month or one-year schedule slip puts the subcontractor in a precarious position. Workers already hired cannot be told to come back in a year when they will actually be needed, nor can contracts for raw materiel already ordered be turned off. As a result, the subcontractor must keep and pay the people already hired and probably pay penalties for changing the raw materiel contracts. In times past the subcontractors could shift the workers to other programs temporarily, but in these days of reduced defense spending, that is often no longer possible. Therefore workers, although probably under utilized, are kept on the payroll until they are needed. Because of the way contracts between the prime and subcontractors are written, many of the costs will be passed back to the prime. The exact impact depends, of course, on how much lead time is required by each subcontractor. At the time of the rephasing some were not even on contract yet, while others had only begun ramping up, so the full extent is impossible to quantify. However, it is probable that the impact on efficiency is substantial.

Even more harmful perhaps is the effect the resulting schedule slips have on prime-subcontractor relations. The prime is being squeezed by the government to reduce costs, yet with as much as 80 percent of the vehicle manufactured by subcontractors, the prime has no other option but to try to force the subcontractors to absorb the cost and schedule impacts resulting from government funding cuts. The subcontractor, well aware of the decreasing defense work, may feel there are no other options, and therefore agree. Yet this hardly leads to the type of relationship between prime and subcontractor enjoyed within the Japanese automotive industry; indeed, it is reminiscent of mass production at its worst.

Industry and government program managers are well aware of the problems created by changing vendor contracts and have avoided doing so whenever possible. However, that leaves engineering and manufacturing as the only areas where money can be saved. Design engineers are already working on finalizing the design and therefore cannot be laid off and then rehired again when needed. Manufacturing, on the other hand has not yet begun, so it relatively easy to delay tooling and put off hiring factory workers until later in the program. This inevitably adds to the overall cost, $714 million in the case of the rephasing effort, and is detrimental to efficiency. For example, Lockheed has delayed hiring the manufacturing engineers needed to design and draw the tooling by nearly a year. Hence end-item design and tooling design that should be accomplished concurrently will now have to be done sequentially in many cases. As a result, at the critical design reviews for many of the subsystems occurring during the summer of 1994, government and company engineers will have only tooling concepts to review, rather than actual drawings. At this point, it is impossible to calculate the inefficiencies and mistakes that will result, not to mention the lost benefits that come from the synergism when detailed manufacturing design is done during early phases.

As this paper is being written, the F-22 program is going through yet another rephasing effort. When the FY 1994 budget was passed, Department of Defense officials noted Congress had inadvertently cut another $163 million from the F-22 budget. While no one is presently sure why the money was cut -- there was no language to explain the reduction -- program officials are wrestling with how to make ends meet. With the fiscal year already one quarter over, it is even more difficult to find ways to adjust the funding profile to meet the cut. To make matters worse, program officials were told to expect another $100 million cut in FY 1995.

Congressionally mandated changes in requirements are already having an impact on the F-22. In late 1993, months after the F-22 successfully passed a preliminary design review, thus settling on a baseline approach, Congress mandated the F-22 should also have air-to-ground capability. This requirement did not come from the user, Air Combat Command, nor was it driven by changes in the threat to the United States. Rather, several Congressmen felt that for the amount of money the F-22 would cost, it should have an air-to-ground capability. They evidently did not realize that efforts in the past to make fighters jack-of-all-trades have resulted in designs that are not particularly exceptional at anything. The result on the F-22 program is expensive and time-consuming design changes that will ultimately cost nearly a billion dollars and delay the program several months.

Congressional interference has even extended to lean manufacturing itself. In the language of the 1994 Appropriations Bill, Congress withheld $200 million until F-22 program managers could convince them that building hard tooling during EMD for use in production was wise. This, of course, is one of the fundamental principles of lean manufacturing and has been successfully used by lean auto producers for years. Congressional staffers, less knowledgeable in modern manufacturing techniques, advised elected officials that this was risky and that the design would be less able to accommodate late changes in requirements, such as the addition of the air-to-ground mission. While it is true that early purchase of hard tooling makes late design changes difficult and expensive, the entire lean manufacturing process ensures that any design changes that result from refinements as the design matures will be minimal. Of course no process, including lean manufacturing, can account for changes in requirements that have not yet been identified, and therein lies the crux of the problem. At the time this paper is written, this has not been resolved.

CHAPTER VI

LEAN MANUFACTURING IN THE EUROPEAN DEFENCE INDUSTRY

Several European defense firms are also striving to implement lean manufacturing. Facing a declining, yet increasingly competitive market similar to that troubling American firms, some see lean manufacturing as a means to continued survival.

GEC-Marconi, a British subcontractor to Lockheed who produces the Head-up Display (HUD), Integrated Control Panel, side stick controller, and flight control computers for the F-22, is now working to adopt lean production, as they refer to it. They report they have been involved in the implementation process for about five years. It appears full implementation is still far from complete, although they are actively employing many lean manufacturing techniques. They use Statistical Process Control (SPC) to detect and track problems, and believe it works better than in the past when judgment was based more on instinctive evaluation. They use Integrated Product Teams with each team responsible for its project, different from the past when a group might have a functional part of ten projects, but no overall responsibility for any of them. They recognize the importance of one line of authority, and said their team leader is the one person who calls the shots. They have implemented the Projects Directorate, which exists as a corporate advisory board to assist the product teams. All the members have significant experience that they believe adds credibility. They employ process verification instead of inspections for quality control, and are quite pleased with the results. As one company official commented, "It makes sense because you often cannot test the complicated things, which means you tend to end up testing only the easy things." They have downsized significantly as part of their strategy for coping with reduced purchase quantities in the future. Going from 16 to 2 production shops, they now have the same people doing multiple jobs, as opposed to people being dedicated to just one task. They report an excellent rapport with organized labor, which would seem to indicate they have done a good job communicating the nature of the changes, and the reason for change -- which they state quite simply was survival.

Inventory and supplier relationships were subjects of particular interest to them. In terms of Just-In-Time[72] delivery, they expressed reservations because the concept carries risks. They said they would like to think their situation is not as bad as "just in case" inventory, but acknowledge that they are not at the JIT point yet. They also do not see JIT as necessarily the total answer. While it works well if applied to high volume items with at least a month lead time, they said it sounds better than it works for special components. They make the point that JIT production is not realistic because many special components cannot be cost-effectively manufactured in small enough quantities to match their requirements. Hence, special components tend to be produced in larger groups, and then held by the supplier until required. This produces the appearance of JIT production, but represents no change from past practices. GEC personnel think a better idea is to move toward disciplined common components, so the same item will fit a range of programs.

Supplier relationships have changed in several ways. The rapidly reduced platforms and numbers of end items to produce have made it impossible to sustain as many suppliers as in the past. Some suppliers have gone out of business. GEC has cut others, and is in the process of eliminating more. Their emphasis is on long-term relationships and they now approach it as more of a partnership. However, they have grave reservations in this area, because cutting the supplier base carries risk. They fear that if there is only one supplier of a necessary item, that firm can charge whatever it chooses, knowing the customer has no viable alternative other than to pay the price demanded. GEC was more optimistic about the quality issue with suppliers. Supplier certification is becoming more the rule, and quality control inspections are being reduced. GEC has firmly accepted the idea that quality must be built in, that it cannot be inspected in.

As a subcontractor to Lockheed, GEC-Marconi is contractually committed to formulate an F-22 Lean Enterprise Company Plan, however they have not yet done so in February 1994.

In summary, GEC-Marconi sees continued survival as depending on winning new business, structuring to do the business they have, and being responsive to their customers which will attract business. Lean manufacturing in one way they are striving to produce a high quality product and be responsive to the ne :s of their customers.

British Aerospace Defence Dynamics (BAe) has analyzed their situation thoroughly, and changes based on principles of lean manufacturing are part of several options they have pursued in their efforts to ensure the continued survival of their company. BAc believes aerospace defense firms have only a small group of business considerations (variables) to balance.[73] They are: Supply, Demand, Politics and Technology. There are a number of interrelated strategic issues associated with these considerations. In terms of "Supply," there currently exists significant overcapacity based on the "Demand" for military aircraft which has been volatile, but in slow decline since the 1960s. Contributing to that decline, changing "Politics" prompt leaders to perceive a reduced threat, minimum force needs, increased development costs and budget pressures as reasons to reduce aircraft acquisition. "Technology" changes also affect aerospace companies. There has been a significant shift in where value is added, causing companies to refocus. In 1960, construction of an airframe represented 40 percent of the value added in the production process. In 1990, the airframe represents only slightly more than 20% of the value, while engine(s), avionics and integration each represent larger proportions of the value added.

Based on these considerations and strategic issues, BAc has identified six major threats they believe endanger their existence. Markets have moved from slow decline to rapid fall-off. Development costs continue to accelerate, further damping demand. The technology gap may be widening between major competitors. Smaller scale production increasingly exposes cost disadvantages for individual manufacturers. Airframe prime contractors are suffering from the erosion of their value added share. Exports may be compromised by joint development and production arrangements.

BAc leaders have conceptualized the following as possible survival options:

(1) Shut Down - Exit unprofitable sector.

(2) Strip Down - Reduce cost base to remain profitable and create more opportunities.

(3) Sell - Capitalize shareholder value, and generate funds to invest in creating a more focused critical mass that can concentrate on core competence.

(4) Swap - Exchange/merge assets to create a market leader.

(5) Spin-Off - Create a profitable stand-alone activity that is better structured to sustaining and winning business.

BAc leaders have adopted many of these options, to varying degrees. They have shut down facilities, downsizing from 16 sites in 1988 to 3 sites in 1994. They have stripped down, reducing their cost base significantly by going from 16,500 employees in 1988 to approximately 4,000 in 1994. They sold BAc Corporate

Jets Division to Raytheon for $0.375 billion in 1993. They employed the concept they call spin-off in creating BAe Military Aircraft Software System.[74] The actions described above are what they have done. Through it all, lean manufacturing has been a major part of their strategy for how to do what was necessary.

Valuable lessons can be drawn from their experience, in terms of what they found most important as they set about the ongoing process of employing the principles of lean manufacturing. The benefits they have realized also merit close scrutiny. First and foremost, they treat human resources as the most important factor. They consider open communication at every level their top priority. Information must flow freely between groups as well as individuals. Managers, workers, union representatives, team leaders and team members as well as customers must be kept informed. Among the lessons they learned was impart the vision to all constantly, and act early; do not ignore problems and difficulties. Foster open communication of problems, the need for action, and the timetable for that action. Employee involvement is crucial at every level, so everyone knows what is going on, and there are no surprises. They also emphasized communication flow in external dealings, so customers also know what is happening. Reorganization must not be used as an excuse for poor performance. Rather, customers should understand the objectives, so they can measure progress. Trust and creditability between management, the labor force, suppliers, and customers are all important.

Employee involvement is another crucial component in terms of human resources. Individuals feeling ownership and taking part in setting targets is important to really adopt lean manufacturing. To be successful, the process requires each individual be flexible, develop multiple skills and pursue continuous improvement -- which equates to a sizable commitment. BAe personnel said to be sure to keep telling employees why they are doing what they are doing.

BAe believes strongly that training is a key way to increase human capital. During the first 18 months, they spent 400,000 - 500,000 pounds on training. That included sending managers to Japan for three months to learn lean production practices where they were developed and perfected. Shop personnel received two months of training in England. Focused training continues about lean manufacturing, and particular skills. When employees are reduced, specialists eliminated and workload drops, individuals must be multi-skilled so they can do more jobs than in the past, which requires additional training.

Organizational structure is a second area BAc considers critically important based on their experience. Their recommendation is to strive for a flat, responsive organization with less layers and fewer managers. One of their problems was they began with 11 different layers within their organization. Their advice is reorganize if necessary, so there is a single management team and as many project teams as needed. They have found an organization that is project driven rather than functionally driven to be more effective. They operate with 5 - 50 people in co... teams (or integrated production teams as they are also known), and concentrate on having clear roles and responsibilities. Personality and experience are important factors, but potential as well as past performance was considered in forming teams. They conducted psychometric testing to determine who might be the best team leaders. BAc also realigned their organization to concentrate on creating and developing core competencies. For example, they moved away from work on seekers ("the eyes" of a weapons system) to focus on guidance and control ("the brain" of such a system). BAc leadership has divested the company of non-core product lines. Illustrating this point, they no longer are involved in work related to humanitarian, non-combat roles and missions for the military. The structure of a company affects how they approach everything they do, which makes it an integral component of lean manufacturing.

Associated with how a company is organized is what the company feels is important. BAc specifically focused their priorities on: communication, customers, employees, shareholders, quality, programs, products, and technology. Those priorities did much to shape what and how they conduct business. BAc developed several programs to support these priorities. Cost and performance management is a key area receiving attention. Meaningful measurement based on Key Performance Indicators is a subset of this. They have developed personal and team Performance Objectives. They also concentrate on cost reduction by using Activity Based Costing that analyzes where the most significant cost of producing an item occurs.

BAc also emphasizes their Performance Improvement Program. They have institutionalized the idea that time must be dedicated to the effort for performance improvement to be realized. They hold a 5 minute meeting every day at 2:00 P.M. to discuss how to fix problems experienced that day, and 20 minutes are allotted to fix each day's problems. Every second week, they schedule a four-and-a-half-day work week, with the remaining half day reserved for "working fixes." If the time is not needed to solve problems, it is used for ongoing training. Employee involvement, focused training, continuous improvement groups and open communication are crucial.

Quality and non-conformance issues are addressed in several ways as part of their Performance Improvement Program. SPC is employed to identify processes needing attention. Quality control inspections have been greatly reduced. Replacing inspections is rigorous product certification which integrates inspection of the product and inspection of the processes used to produce the item. When they have confidence in the production techniques as well as the product, inspection is accomplished only occasionally on a random basis. This has affected BAe's relationships with suppliers as well. BAe saves time, money and energy by inspecting on only a random basis those second- and third-tier suppliers who have quality in place and meet certification standards.

BAe's treatment of inventory is a final area worth examining, especially since they depart from the lean manufacturing principle of Just-in-Time. BAe has found Just-in-Time production to be too hard to work with. Instead, they employ an approach they call Just-Enough-Desirable-Inventory (JEDI), which they use to monitor their inventory. It limits the amount on hand, but at the same time it makes slightly more inventory available, which allows more flexibility in the production and deliver process, and provides the prime contractor a safety margin should problems develop with a second- or third-tier supplier.

BAe is extremely positive about the benefits they have achieved using lean manufacturing. When they began, they were experiencing many of the same problems that trouble automobile mass production manufacturers. They were facing steadily increasing competition, and a great deal of customer uncertainty. They had excess capacity, and facilities that duplicated each other. They had extensive inventory on hand. Their programs were years behind. Their manufacturing processes suffered from a lot of waste, low productivity and a lack of value added. Their hierarchical organization consisted of 11 layers which resulted in a slow, unresponsive bureaucracy and high inertia. Understandably, they had a poor reputation among their customers. After having unreservedly adopting lean manufacturing, they are highly satisfied with the results. They are convinced they produce a better product at lower cost because the processes they use are more effective, and less labor is required. The company is concentrating on what it does best, and all the players, labor and management, are involved and working toward continued success.

Applying the principles of lean manufacturing to an aerospace firm may be regarded by some as an experiment. But both GEC-Marconi and BAe saw it as absolutely necessary to their continued survival. Recognizing that all information on this subject has been provided by the companies, and not validated by any

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CHAPTER VII

CONCLUSIONS

Striking parallels exist between the American automobile industry of the 1980s and the aerospace defense industry today. The Big Three were unwilling to accept lean production until outside competition and a competitive market allowed no other alternative. In the aerospace defense industry today, shrinking orders and intense competition are producing a similar effect. There are no technical reasons why lean production cannot make the same dramatic improvements in productivity and quality in the defense industry as it did in the automobile industry. In fact, because of the extreme complexity of aircraft, the interdependence of the many subsystems, and the higher skill and education levels of the aerospace worker, the benefits may be even greater.

Two main issues remain unresolved that may determine whether lean manufacturing enjoys the same success in the aerospace defense industry as it did in automobile manufacturing. Although some motivation certainly exists, it is not clear the incentive in this country is sufficient for the companies to make the sweeping changes demanded by lean manufacturing. Even the F-22 EMD program at Lockheed Aeronautical Systems Company, which is at the leading edge of lean manufacturing expertise in the United States, has not yet made all the fundamental changes required. In contrast, the European aerospace firms of GEC-Marconi and British Aerospace have responded to the economic challenges of the 1990s by enthusiastically embracing the concepts of lean manufacturing. British Aerospace, in particular, is well on the way to becoming a lean producer. If the lessons from the automobile industry are any indication, failure to change may be disastrous for both the United States aerospace defense industry and the country.

The second issue is even more important, and unfortunately, totally beyond the control of the aerospace industry. Continual Congressional interference and unpredictable year-to-year funding wreak havoc on the delicate timing demanded by lean manufacturing principles. Given the reality of reduced defense budgets in the coming years, lean manufacturing may have a difficult time proving its value, and may even be dismissed as just another failed management method. While it may be argued that lean manufacturing makes it easier to adjust to such changes, it must be pointed out that true lean manufacturing is based on concurrency and many events coming together at just the right time. If external factors prevent this from occurring, it is very possible the promised efficiencies of lean manufacturing may never materialize. Until more sweeping changes are made in acquisition processes, the full potential of lean manufacturing may not be realized.

NOTES

1 "Lean manufacturing" is the term used in this paper to describe the processes and procedures used extensively in the Japanese automotive industry. However, "lean production" and "lean enterprise" are other terms used interchangeably in industry and literature on the subject to describe the same concept.

2 James P. Womack, Daniel T. Jones, Daniel Roos, The Machine that Changed the World, (New York: First Harper Perennial Edition, A Division of Harper Collins Publishers, 1991), 3-9.

3 Ibid., 4 (first quotation appearing below), 8 (second quotation appearing below).
The book titled The Machine that Changed the World represents more than five years of research comparing the differences between mass production and lean production in the automotive industry on a global basis. The study was accomplished under the auspices of the International Motor Vehicle Program (IMVP) based at the Center for Technology, Policy and Industrial Development at the Massachusetts Institute of Technology. "The Center had a bold charter: to go beyond conventional research to explore creative mechanisms for industry- government-university interaction on an international basis in order to understand the fundamental forces of industrial change and improve the policy-making process in dealing with change." The study also led the authors, Womack, Jones and Roos, to the conviction that "the principles of lean production can be applied equally in every industry across the globe and that the conversion to lean production will have a profound effect on human society -- it will truly change the world."

4 Ibid., 30.

5 Ibid., 21-22.

6 "A Survey of the Car Industry" The Economist, (October 17, 1992), 5.

7 Womack, 27.

8 Ibid., 27-28.

9 Ibid., 37.

10 Ibid.

11 Ibid., 29.

12 Ibid., 30.

13 Ibid., 28-31.
A 1915 survey revealed the more than 7,000 assembly workers at Ford's Highland Park plant in Detroit spoke more than fifty languages with many of them barely speaking English.

14 Ibid., 42-43.

15 Ibid., 31-?

16 Yasuhiro Monden, Toyota Production System, (Norcross, Georgia: Second Edition, Industrial Engineering and Management Press, 1993), 336.

17 Captain Denise Carnejo, "ASC Launches Initiatives to Improve Development of Aerospace Systems" United States Air Force News Release, PAM# 93-096 (May 14, 1993): 10.
"It's 'lean' because it uses less of everything needed in mass production -- half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product, and done in half the time."

18 Womack, 48-49.

19 Ibid., 277.

20 Ibid., 247-248.

21 Ibid., 247.

22 Monden, 343.

23 Womack., 54.

24 Monden, 343.

25 Ibid.

26 Ibid., 344.

27 Ibid., 347.

28 Womack, 251.

29 Ibid., 53.

30 Monden, 346.

31 Womack., 79.

32 Ibid., 99.

33 Ibid., 225.
34 Ibid., 57.
35 Ibid., 56.
36 Ibid., 57.
37 Ibid., 64.
38 Ibid., 81.
Source: 1986 World Assembly Plan Survey accomplished as part of the International Motor Vehicle Program reference in earlier endnote.
39 Ibid., 82.
40 Ibid., 79.
41 Ibid., 62.
42 Monden, 337.
43 Ibid., 339.
44 Ibid., 59.
45 Womack , 61.
46 Ibid., 61.
47 Ibid. 67.
48 Ibid., 112-118.
49 Ibid., 98.
50 Ibid., 111.
51 Ibid., 110-111.
A worldwide survey conducted at the Harvard Business School examined product-development activities in the motor industry during the 1980s time frame. Twenty-nine development projects for cars with totally new bodies (although some used carryover or shared internal components) which were marketed between 1983 and 1987 were examined. Some adjustments were made to make the terms of comparison as equitable as possible. The results showed a totally new Japanese car took an average of 1.7 million hours of engineering effort, and 45 months from design to delivery. American and European projects of similar complexity required 3 million engineering hours and 60 months.
52 Anthony L. Velocci, Jr., "Grumman Will Abandon Critical Airframe Skills" Aviation Week & Space Technology (October 18, 1993), 33.
53 Lean Aircraft Initiative Briefing by Nitin C. Shah, Project Officer, Wright Laboratory, Material Technology Division, Wright-Patterson Air Force Base, Ohio.
54 Sue Baker, "Lean Aircraft Initiative" Leading Edge (January 1994), 14.
55 Sources vary as to the number of commercial participants. Nitin C. Shah cited 21 companies in his Lean Aircraft Initiative Briefing. John D. Morrocco said 25 companies were participating in his May 24, 1993 Aviation Week & Space Technology article, page 23. Dr William Kessler referenced 18 companies in a January 1994 Leading Edge article, page 14. United States Air Force News Release, PAM # 93-096, of May 14, 1993 listed the following 22 participating companies: AIL Systems, Allied Signal, Boeing Defense & Space, GE Aircraft Engines, Grumman, Honeywell, Hughes Radar Systems, IBM Federal Systems, Lockheed Aeronautical Systems, Loral Defense Systems, Martin Marietta, McDonnell Douglas, Northrop, Pratt & Whitney, Raytheon, Rockwell-North American Aircraft, Sundstrand, Texas Instruments, Textron Defense Systems, TRW, Vought Aircraft, Westinghouse Electronic Systems Group.
56 John D. Morrocco, "USAF Aim: Lean Production" Aviation Week & Space Technology (May 24, 1993), 23.
57 Sue Baker, "Lean Aircraft Initiative" Leading Edge (January 1994), 14.
58 Ibid.
59 Morrocco, "USAF Aim: Lean Production," 23.
60 Ibid., 24.
61 LEANAIR Newsletter of the Lean Aircraft Initiative, M. I. T. (Summer 1993, Vol. 1, No. 1), 2.
"In conjunction with the Lean Aircraft Initiative's 22 industrial sponsors, a consortium of MIT departments and centers involved in systems and manufacturing education have teamed to develop the Systems Engineering and Manufacturing Productivity Institute (SEMPI). The proposed educational offering is designed to meet the critical technical and management retraining needs of the US aircraft industry. . . . Providing a pioneering framework for the understanding and dissemination of lean principles and practices, SEMPI will involve a rigorous program of

instruction at MIT, covering such topics as systems engineering, flexible manufacturing, integrated product and process development, emerging critical technologies and related subjects, combined with a case study-based practicum at sponsors' plants. Industrial sponsors have pledged their support both through a reassignment of sponsor funds and an offering of 'in kind' assistance in development of the program, course materials, and case studies. Dr. Stanley Weiss explains, 'Aiming towards a master's degree in systems engineering and manufacturing-related technology, the program would take advantage of lessons learned in the Lean Aircraft Initiative and provide students insights into real productivity measures.' . . . The education afforded by SEMPI will provide direct benefit to both sponsoring companies and to the development of paradigms for the aircraft industry."

[62] UPdate, Department of Aeronautics and Astronautics, M.I.T. (Winter 1994).

[63] Morrocco, "USAF Aim: Lean Production," 24.

[64] UPdate, (Winter 1994).

[65] LEANAIR Newsletter of the Lean Aircraft Initiative, M.I.T. . (Summer 1993, Vol. 1, No. 1) 1, 3. Research Projects inwork or underway in designated focus areas are as follows.
Product Development:
1) Integrated Product and Process Development: Models, Practices and Metrics
2) Process Flow Modeling and Analysis
Fabrication and Assembly:
3) Inventory and Buffer Practices
4) Fabrication and Assembly Workflow Organization, Materials Management and Logistics
5) Make-Buy Decisions, Supplier Selection Criteria, Current Best Practices and the Impact of Government Regulations on Supplier Relationships
Organization and Human Resources:
6) Concurrent Right-Sizing and Human Resources Management
Policy and External Environment:
7) Reforming the Acquisition Process: Institutional Issues and Options

[66] LEANAIR Newsletter of the Lean Aircraft Initiative, M.I.T. (Autumn 1993, Vol. 1, No. 2) 1, 6.

[67] Baker, 16.
John Fialko, a program manager at Hughes Company, El Segundo, California is extremely optimistic. He says, "LAI could well be the most important contribution ever made to integrated process and product development. It has the potential to benefit the entire defense acquisition pipeline, from concept through demonstration/validation, from engineering and manufacturing development through production, from field support through product retirement. The beauty of LAI is that it uses all the elements of balanced design in a disciplined, repeatable way of doing product creation."

[68] F-22 Lean Enterprise General Plan, 25 September 1993. Approved by W. N. Bylciw, Vice-President, F-119 Program and L. G. Riley, Vice-President and General Manager, F-22 Program, 1.

[69] Lockheed Fort Worth Company (LFWC) was formerly General Dynamics Fort Worth Divi[illegible] [illegible]ortly after winning the F-22 EMD contract, Lockheed Corporation bought General Dynamics Fort Worth [illegible]ision. Thus LFWC and Lockheed Aeronautical Systems Company (LASC) are separate companies, both owned by Lockheed Corporation. The actual F-22 contract is with Lockheed Corporation

[70] F-22 Lean Enterprise Company Plan, Lockheed Corporation, Lockheed Aeronautical Systems Group, Lockheed Aeronautical Systems Company, 25 September 1993. Approved by A. L. Pruden, Lockheed F-22 Program Manager.

[71] John D. Morrocco, "Lockheed Concentrates on F-22 Risk Reduction" Aviation Week & Space Technology (September 6, 1993), 50.

[72] Just as the terms lean manufacturing, lean production and lean enterprise are used interchangeably, the term Just-In-Time (JIT) is linked as an adjective to four words: production, inventory, delivery and supply. All four terms are used to describe the idea of producing and delivering just enough inventory to supply precisely what is needed for a short period of end item production. Different authors appear to use the terms interchangably.

[73] Information regarding aerospace companies' situation and options is drawn from the "1994 Strategic Issues Briefing" presented at British Aerospace (Military Aircraft) Ltd., on 15 February 1994, Lancashire, England.

[74] It should be noted that this meaning is different from that associated with the American concept called "spin-off."

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