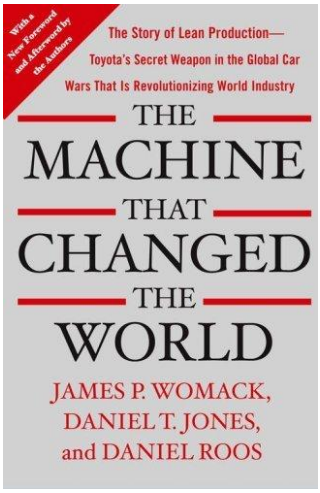
DEFENSE SYSTEMS MANAGEMENT COLLEGE

MANUFACTURING MANAGEMENT DEPARTMENT

TEACHING NOTE

George A. Noyes III, 2002

The Machine that Changed the World (Synopsis)



"The Machine that Changed the World" was written by the three senior managers from the Massachusetts Institute of Technology. The International Motor Vehicle Program (IMVP) was formed in 1985 to study the auto industry. The charter of the center was 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 facing the world motor-vehicle industry.

In studying the automobile manufacturing processes, the IMVP realized their success depended on thoroughness, expertise, a global outlook, independence, industry access and continuous feedback. They had to examine the entire set of tasks necessary to manufacture a car: marketing, design, detailed engineering, coordination of the supply chain, production, and sales and service. This research was conducted by an international team (Japan, Europe, and America) of researchers in academia who had come from the world of industry.

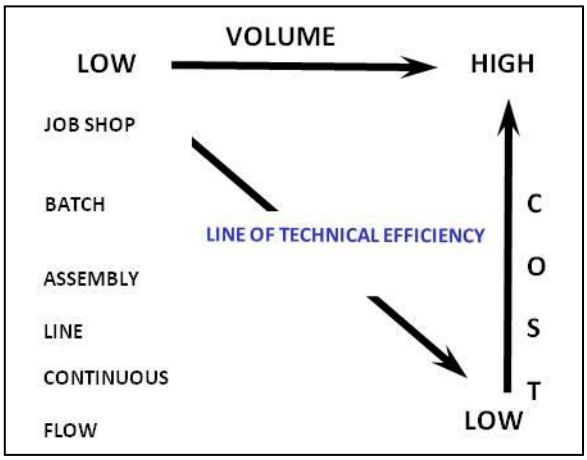
Funding for the $5 million project came from contributions from many car companies, components suppliers, and governments. Contributions from individual companies and governments were limited to 5% of the $5 million total, thereby eliminating national or regional pressures in the conclusions that were ultimately drawn.

IMVP was given extensive access to motor vehicle companies across the world, from the factory floor to the executive suite. They were amazed by the spirit of professionalism that was exhibited by the entire industry and which moved managers in the worst facilities and weakest companies to share their problems frankly, and managers in the best plants and strongest companies to explain their secrets candidly.

This book is the conclusion drawn by the three directors who spent five years exploring the differences between craft, mass and lean production. The authors concluded that the auto industries of North America and Western Europe were relying on techniques that had changed very little from the days of Henry Ford's original mass production system and that those techniques were simply not competitive with the new set of ideas pioneered by Japanese companies (namely Toyota), which they subsequently named "lean production."

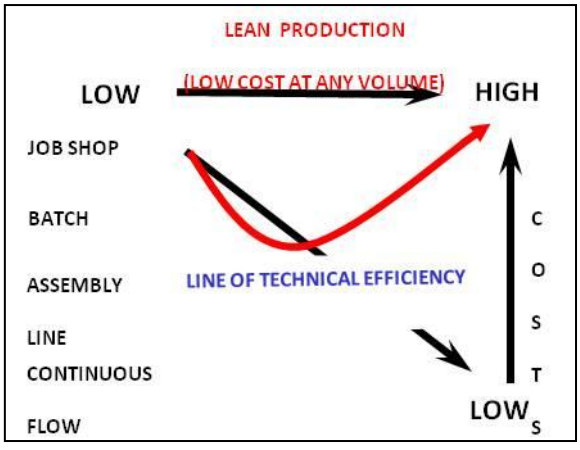
The best way to describe lean production is to contrast it to its predecessors: craft production and mass production. Craft production uses highly skilled workers and simple tools to make

what the consumer wants, one item at a time. Quality was inherent in the skill of the craftsman. Using the guild system the organizations were decentralized. In fact in the early 1900's there were over 300 companies that made automobiles in the U.S. alone. The result of using a craft system is that consumers get exactly what they ask for but at a very high cost. Mass production on the other hand uses narrowly skilled professionals to design products made by unskilled or semiskilled workers tending expensive, single-purpose machines. The machines produce standardized products in very high volume. Due to the high cost of disruption of the process, the mass producer adds many buffers - extra supplies, workers and space - to assure smooth production. Also due to high cost of changing over to a new product, the mass producer keeps standard designs in production for as long as possible. The result is the consumer gets lower costs but at the expense of variety, and workers tend to find their part of the process boring. The conventional belief under mass production is that in order to achieve efficiency you need to be able to produce in large lot sizes. Economies of scale and the theoretical notion of a line of technical efficiency shows that as you move from a low volume (job shop) environment to a high volume (mass production) your unit cost go down.



The Japanese found that by utilizing Lean Principles and Lean Thinking they have changed that model so that unit costs can now become more independent of volume. So why study Lean thinking and Toyota's production system. The answer is that much of what we know today about manufacturing we learned at the knee of the auto industry. As we watched the auto industry move from a craft environment to mass production and now to "lean production" we can begin to understand the dynamics that lean thinking has had on how we approach the factory floor and how that impacts quality, reliability, customer satisfaction and profit.

Lean production, by contrast, uses teams of multiskilled workers at all levels of the organization, and uses highly flexible, increasingly automated machines to produce large volumes of products in enormous variety. The term "lean" comes from its using half the human effort in the factory, half the manufacturing space, half the investment in tools, and half the engineering hours to develop a new product in half the time.



The most striking difference though between mass and lean production is that mass producers set a goal for themselves - "good enough." To do better would cost too much or

exceed inherent human capacities. The lean producer, on the other hand, sets his sights on perfection, thereby delivering ever-increasing benefits. Lean production also pushes responsibility farther down the organizational ladder, to individual workers.

Lean production also calls for individuals to learn a vast number of professional skills and apply these creatively in a team setting. This contrasts with the traditional ideas of career pathing, where an individual develops higher levels of technical knowledge and proficiency in an ever-narrowing area of specialization. The paradox is that the better you are at teamwork, the less you may know about a specific, narrow specialty.

The Origin of Lean Production

Henry Ford created the Model T in 1908 - his 20th design over a five-year period. He had, in the Model T, finally met two objectives: a car that was designed for manufacture and was user-friendly (almost anyone could drive and repair the car). The key to mass production wasn't the continuously moving assembly line, as many people believe, but rather the interchangeability of parts and the simplicity of attaching them to each other.

In craft production, each piece is created by an individual craftsman using his own gauging system in manufacturing the part. Once parts were created, the first piece and the second piece were put together with filing and adjustments made until they fit perfectly. Then the third piece was added and adjusted accordingly, and so on, until an entire automobile was assembled. Each piece was then fired for hardness. This usually warped the metal and the piece had to be machined again to regain its original shape. The end result was that no two parts were ever the same, thus making parts replacement or interchangeability impossible.

To achieve interchangeability, Ford insisted that the same gauging system be used for every part all the way through the entire manufacturing process. Ford also benefited from the recent development of pre-hardened metals. Taken together – interchange-ability, simplicity, and ease of attachment - Ford was able to eliminate the skilled fitters who had always formed the bulk of every assembler's labor force, giving him an advantage over his competition.

In 1913, Ford introduced the first moving assembly line in the Highland Park plant in Detroit. Rather than individual workers creating one whole automobile before beginning another one, he had honed the concept of the worker remaining in one spot and the product, components and tools would come to the worker. This created the concept of the unskilled worker who no longer needed to understand the whole production process but merely needed to be able to attach two screws to two nuts or put one wheel on every car that came by all day long. He had not only created the interchangeable worker.

Henry Ford
(1900 - 1920)

- Interchangeable Parts
  - Single Gaging System
- Simplicity of Design & Ease of Assembly
  - Easy to Maintain
  - 1908 Model T (514/minutes cycle time)
  - 1913 Model T (2.3/min.)
- Moving Assembly Line
  - Single Task per Assembler (1.19/min.)
- Vertical Integration
  - Tolerances & Scheduling
- Lots of Support Workers
  - Tooling, Quality, Foreman, Expediters, etc.

By 1915, Ford had further streamlined the process to include the vertical integration of supplies. Rather than buying his chassis and engines from the Dodge brothers (as he had been doing) and a host of other products from other firms, he brought all these functions in-house. The decision was made partly because Ford had perfected mass-production techniques before his suppliers and could achieve substantial cost savings by doing everything himself. He also trusted no one but himself. Lastly, he needed parts with closer tolerances and on tighter delivery schedules than anyone had previously imagined. So he replaced the mechanism of the market with the "visible hand" of organizational coordination.

By the early 1920s, General Motors was also in the running as a mass producer of automobiles. Unfortunately, its founder, William Durant, was a classic empire-building man; he had no idea how to manage anything once he bought it. He was ousted from management by his bankers in 1920, and replaced by Alfred Sloan. In order to manage the five major companies owned by General Motors, Sloan developed the principal of managing objectively "by the numbers." Sloan and the other senior executives oversaw each of the company's profit centers by evaluating detailed sales, market share, inventory, and profit and loss reports. Sloan felt it unnecessary for executives to understand the details of operating each division. The numbers would show performance; if performance was down, it was time to change the general manager, if it was good, the manager was a candidate for promotion to the vice-presidential level.

SLOAN
1920-30's

- 12 Car Companies
  - Managed Separately
  - High Degree of Product Overlap
- Decentralized
  - 5 Car Companies, One for every pocketbook
- New Breed of Professionals
  - Finance & Marketing
  - Management By-the-Numbers
  - Stovepiped Top-to-Bottom
- Standard Mechanical Parts for all Cars
- Endless Series of Add-On Features
  - Internal Self-Starter, Radio, Heater,
- Roll-Up Windows, etc.

Sloan used the same decentralized management theories across the entire company, domestically and internationally, as well as across disciplines. He essentially developed the last part of the division of labor that Ford had begun. Ford had developed the rework specialist and general foreman of the assembly line, to manage the errors of the interchangeable worker, and the engineers to design the product and processes. Sloan added the financial manager and marketing specialist to control the rest of the corporate structure. This was the completion of the entire mass production process.

While mass production was being perfected in the US, it was also beginning to flourish in Western Europe. In the late 1950s, VW, Renault and Fiat were producing at a scale comparable to Detroit's major facilities. A number of the European craft production firms also made the transition to mass production.

By the 1970s, the Europeans were specializing in cars very different from Americans though. They were offering compact, economy cars, such as the VW Beetle, and sporty, fun-to-drive cars, such as the MG. They were also developing new product features including front wheel drive, disc brakes, fuel injection, unitized bodies, five-speed transmissions, and engines with

high power-to-weight ratios. Unfortunately, their production systems were nothing more than copies of Detroit's but with less efficiency and accuracy.

In the spring of 1950 a young Japanese engineer, Eiji Toyoda, set out on a three month pilgrimage to Ford's Rouge plant in Detroit (Ford invited large numbers of engineers from around the world to visit his plant; he kept no secrets about mass production). The Rouge plant was the largest, and most complex in the Ford family, if not the world. After much study, he went back to Japan and with the help of his production genius, Taiichi Ohno, they soon concluded that mass production would never work in Japan. From this tentative beginning was born what Toyota came to call the Toyota Production System, and ultimately "lean production."

Toyota faced a host of problems in Japan. Their domestic market was tiny and demanded a wide range of vehicles from luxury cars for executives, to large and small trucks for farmers and factories, and small cars for the crowded cities and high energy prices. The native Japanese work force also was no longer willing to be treated as a variable cost or as interchangeable parts. Japan also did not have the advantage of "guest workers" (that is temporary immigrants willing to put up with substandard working conditions in return for high pay) such as had been available in America and in Europe.

The first process that Ohno tackled was stamping of sheet metal. Until now, the standard practice had been to stamp a million or more of a given part in a year. Unfortunately, Toyota's entire production was to be a few thousand vehicles per year. Ohno concluded that rather than dedicating a whole set of presses to a specific part and stamping these parts for months or even years without changing dies, he would develop simple die change techniques, and change dies frequently (every two to three hours, versus two to three months) using rollers to move dies in and out of position. This way he would need only a few presses rather than a large number of them, and he found it was actually cheaper to produce a smaller number of parts and not have to inventory them.

Not only did he save on the cost of inventory, but mistakes were also caught much earlier in the process. He also hit upon the idea of letting the production workers themselves perform the die changes instead of needing specialists to perform these tasks.

<u>Lean production - company as community</u>

Ohno realized though, that in order to achieve success in his new process, workers would need to be motivated to look for and correct mistakes and to be extremely skilled in their work at the same time. If workers failed to anticipate problems before they occurred, and didn't take the initiative to devise solutions, the work of the factory would come to a halt.

As it happened, his work force acted to solve this problem for him in the late 1940s. Due to problems with the Japanese economy, Toyota was facing a deep slump in business. The company was looking at firing one quarter of the work force. However, the company's union was in a strong position and chose to strike. The result of the negotiations was that the company and the union worked out a compromise that today remains the formula for the labor relations in the Japanese auto industry. One quarter of the work force was let go, but the remaining employees received two guarantees. One was for lifetime employment. The

other was for pay steeply graded by seniority rather than by specific job function, and tied to company profitability through bonus payments. Toyota was promising lifetime employment, but in return they were expecting that most employees would remain with Toyota for their working lives. This was a reasonable expectation, because by leaving companies and starting over again, a worker would lose his seniority.

Workers also agreed to be flexible in work assignments and to be active in promoting the interests of the company by initiating improvements rather than merely responding to problems. In effect, the company officials felt that if they were going to take on an employee for life, the employee would have to do his part by doing the jobs that needed to be done.

Lean production - assembly plant

Ohno then went on to rethink the assembly process. He chose to regroup the assembly workers into teams. Where Ford had given the jobs of housekeeping, tool repair and quality checking to independent specialists, Ohno gave these responsibilities to each team. Where Ford had felt that it would be better to let a mistake go through to the end and have a rework specialist correct an error, Ohno felt that rework was merely a costly addition that was unnecessary. Instead, Ohno placed a cord above every workstation and instructed workers to stop the whole assembly line immediately if a problem emerged that they couldn't fix. Then the whole team would come over to work on the problem.

He also instituted a system of problem solving called "the five why's." Workers were taught to trace every error back to its ultimate cause, then to devise a fix so that it would never occur again. By the time Ohno's system hit its stride, the amount of rework needing to be done was minimal. Workers were able to catch almost every error as it occurred. The quality of cars shipped also steadily improved. This was because quality inspection, no matter how diligent, simply cannot detect all the defects that can be built into today's complex vehicles.

Today, Toyota's assembly plants have almost no rework areas. By contrast, the number of current day mass production plants devote 20% of plant area and 25% of their total hours of effort into fixing mistakes.

Lean production - supply chain

The next part of the process that Ohno tackled was the supply chain. Where mass producers typically sought bids on a given number of parts from outside firms and internal divisions, the lowest bidder usually got the business. A bidding firm typically was given drawings and told to quote on a given number of part of a given quality. Supplier organizations working to blueprint had little opportunity or incentive to suggest improvements in the production design. Usually, suppliers were given little to no information about the rest of the vehicle, and therefore could not really offer suggestions for improvement, whether based on their own ideas, designs or previous experience.

Ohno also felt there was a problem coordinating the flow of parts within the supply system on a day-to-day basis. The result was high inventory cost, and routine production of thousands of parts that were later found to be defective when installed, based on the fact that they were stamped repeatedly in large quantities without being checked until they got to the

factory weeks or months later.

Ohno chose a totally different approach. He gave a potential supplier performance specifications; for example, he told a potential supplier to design a set of brakes that could stop a 2,200 lb. car from 60 miles per hour in 20 feet, ten times in succession without fading. The brakes would have to fit into a space 6' x 8' x 10' at the end of each axle and be delivered to the assembly plant for $40 a set. This system would also have to work in harmony with the other systems of the car. Toyota didn't tell a supplier what they were to be made of or how they were to work. Those engineering decisions were for the supplier to make. In this way, suppliers were able to help improve the design process.

These suppliers were called first-tier suppliers. They were then responsible for establishing second-tier suppliers under themselves. These were the companies that were assigned the job of fabricating the individual parts. While Toyota did not wish to vertically segregate its suppliers into a large bureaucracy, it also did not wish to deintegrate them into completely independent companies. Therefore, Toyota spun off its in-house supply operations into quasi-independent first-tier supplier companies, in which Toyota retained a fraction of the ownership and developed similar relationships with outside suppliers who had been independent. Toyota still holds a percentage of ownership in a number of its former in-house supplier companies. Because Toyota does not own them wholly, these firms have substantial cross-holdings in each other and they also provide supplies to companies other than Toyota and to firms in other industries. At the same time, these companies are intimately involved in Toyota's product development and accept Toyota people into their personnel systems. In a very real sense, they share their destinies with Toyota.

Finally, Ohno developed a new way to coordinate the flow of parts within the supply system on a day-to-day basis, the famous just-in-time system. It was a simple idea, but very difficult to implement because it practically eliminates all inventories. When one small part of a vast production system fails, the whole system can come to a stop. It also removes all safety nets and focuses every member of the vast production process on anticipating problems before they become serious enough to stop everything.

<u>Lean production and engineering</u>

Where mass producers have tried to solve the problem of engineering a manufactured object as complex as today's motor vehicle by finely dividing labor among many engineers with specific specialties, Ohno realized that this system had a great number of weaknesses. Ohno by contrast decided early on that product engineering inherently encompassed both process and industrial engineering. Therefore, he formed teams with strong leaders that contained relevant experience in both the manufacturing of a product and the engineering of design. Career paths were restructured for engineers so that rewards went to strong team players, rather than to those displaying genius in a single area of product, process, or industrial engineering.

<u>Lean production and changing consumer demand</u>

By the 1980s, reliability was one of the strongest factors in car purchases. Toyota's lean production system delivered superior reliability. Toyota found it no longer had to match the

price of competing mass production products. Toyota's flexible production system and its ability to reduce production engineering costs allowed the company to supply the product variety that buyers wanted, with little cost penalty.

By 1990, Toyota was offering consumers around the world as many products as GM, even though Toyota was still half the size. To change production and reengineer a new car at GM costs a fortune and takes many years. Toyota can offer twice as many vehicles within the same development budget. As recently as 1987, a manufacturing manager in Detroit stated that the secret to Japanese success was that they are making identical "tin cans." If he did that, he could have high quality and low cost, too. He didn't realize that the Japanese have a very broad portfolio of products, and have reengineered the entire design and production process to produce high variety at a low cost.

Lean production: dealing with the consumer

Lean production means nothing if the producer cannot build what the customer wants. Henry Ford's link to the consumer was simple; there was no product variety and repairs could be handled by the owner, so the job of the dealer was simply to have enough cars and spare parts in stock to supply expected demand. Unfortunately, the assembler used the dealer as a "shock absorber" to cushion the factory from the need to increase or reduce production. This caused strains between the relationship between the dealer and the customer, and the dealer and the factory. Ohno confronted this problem in the same way as the supplier group. He specifically developed the Toyota Sales Company, which was a network of distributors, some wholly owned, and some in which Toyota held a small equity stake. The dealer became the first step in the production system.

Toyota eventually stopped building cars in advance and converted to a build to order system. Dealers helped in sequencing orders by making house calls. They worked more hours when demand dropped and concentrated on households likely to want the cars the factory could build. They especially focused on repeat buyers. Brand loyalty became a salient feature in Toyota's system.

The Elements of Lean Production

The lean factory

Surprisingly, the studies of the IMVP have shown that when comparing the worst American automobile plants to the Japanese or European plants, they don't fare nearly as badly as would have been thought. In 1989, the GM plant in Framingham, MA, which rated the lowest in productivity, still ranked higher than the average European owned plant (the Framingham plant closed in 1989). European plants have now shown to be the home of classic mass production. North American plants have in turn shown that they are adopting many lean production techniques and there are many Japanese transplants in North America that are showing average performance to be similar to that of the average Japanese plant in terms of quality, but lagging by 25% in terms of productivity. The differences are due to different methods of obtaining supplies that necessitate extra work and longer distances. These plants are also still at an early point in the learning curve with respect to lean production. There also is an issue of management; the best performing companies in Japan

run the best performing transplants in North America.

We can no longer equate "Japanese" with "lean production" and "Western" with "mass production." The numbers show that lean production can be practiced far away from Japan. The comparison of automation versus productivity resisted the commonly held beliefs that automation equals productivity. While automation certainly means less effort, is does not necessarily equate into more productivity. Once again, it became a question of manufacturing or designing lean production into the process, before automation is applied. Two organization features of a truly lean plant are transferring the maximum number of tasks and responsibilities to those workers actually adding value to the car on the line and having in place a system for detecting defects and that quickly traces every problem, once discovered, to its ultimate cause. This means teamwork among line workers. Toyota has in place a simple but comprehensive information system that makes it possible for everyone in the plant to respond quickly to problems and understand the plant's overall situation. In the most advanced lean production plant, information is displayed daily regarding production targets, equipment break-downs, personnel shortages, overtime requirements and so forth. Whenever anything goes wrong, any employee who knows how to help runs to lend a hand. In the end, it is the dynamic work team that emerges as the heart of the lean factory. Workers need to be taught a wide variety of skills. They need to be cross-trained in their work group so that they can fill in for each other. They all need the additional skills of simple machine repair, quality checking, housekeeping and materials ordering. They need to be taught to think proactively, so they can devise solutions before problems become serious. This is not the same as merely changing the organization chart to show teams and introducing quality circles.

Opponents feel that lean production is no more fulfilling than mass production. They feel that the stress of constantly looking to eliminate the "slack" forces managers to feel they continually have to identify the slack, and assemblers feel that they are constantly at risk of losing their job. The second critique is of lack of fulfillment, and has been combated with "neocraftsmanship." Neocraftsmanship places larger teams of approximately ten workers together, to create one entire vehicle. This process takes much longer than even mass production. There is a difference between the tension of continually improving the process and the challenge of neocraftsmanship. A properly organized lean production system does remove all slack - that’s why it's lean. But it also provides workers with the skills they need to control their work environment and the continuing challenge of making the work go more smoothly. There is a creative tension for the workers to address challenges, but on the other hand management must offer its full support to make this system work. In automotive market slumps, the company must make sacrifices to ensure job security, because it has promised lifelong employment to workers.

Lean design

The fundamental differences in lean design versus mass production design include leadership, teamwork, communication and simultaneous development. Taken together, these four areas make it possible to do a better job faster and with less effort.

Lean producers invariably employ some variant of the Large Product Leader (LPL), pioneered by Toyota. The idea is that the LPL is the boss, whose job it is to design and

engineer the new product and get it fully into production. This person carries great power and is perhaps the most coveted position in the company. The difference between this mentality and MP, is that in lean production the team leader is the manager with much power. In a mass production system, the leader is more properly termed a coordinator, whose job it is to convince team members to cooperate.

In lean production, there is the element of the tightly knit team. Engineers are assigned to a project for its life, and come from all the functional areas of the company; market assessment, product planning, styling, advanced engineering, detail engineering, production engineering and factory operations. They retain their ties to their functional area, but for the life of the program they are clearly under the control of the LPL. In the mass production system, engineers are loaned to the coordinator, while continuing to be accountable to their normal department manager. Unfortunately, their department is not usually interested in one project, but on the rest of their responsibilities overall.

Communication is much easier within the lean production system, because the team is headquartered in one place. In mass production, the project usually moves from department to department along the process, with team members staying in their own functional areas, therefore being separated from the project. As conflicts or problems occur, they are not usually communicated to the rest the team. There is also a much smaller number of people involved in a lean production team; 485 versus about 900 in a mass production system. The lean production team also agrees at the beginning what exactly everyone's roles and responsibilities are, and signs individual contracts to that effect. Conflicts regarding resources and priorities occur at the beginning rather than midway through or at the end of the project. In the mass production process, no one agrees to anything in the beginning, and at the end, as problems get bigger and bigger, then the disputes begin. Therefore, it takes many more people to correct the problems.

The last element is simultaneous development. In the traditional process, die making does not begin until after product designers give precise specifications. Then steel is ordered, and cut, going through many processes, usually taking approximately two years to complete. In the lean production process, die designers know the approximate size of the new car and the approximate number of panels in advance, because they have been in communication with the rest of the team all along. They order blocks of steel and make rough cuts early on, getting ready for the final design dimensions. While others are still working on the exact specifications, they are beginning and preparing. The process takes about half as much time as does the traditional process.

The last step of the project is actual production. Western analysts have been mistaken or misled by slow start-up schedules of Japanese transplants to North America. They see them as beginning slowly, therefore meaning slow development. What they don't realize is that by ensuring a slow start-up schedule, a new lean production plant can fully master the Toyota Production System. Therefore they stop as necessary to get each step correct, rather than rushing ahead and going back later to rework not just errors, but the entire production process. Once lean production is fully in place in the factory, it is easy to introduce new products developed by the lean production process.

What does this ultimately mean? Japanese producers are tending to replace models of cars

every four years. American mass production companies by contrast are keeping the average model in production for nearly 10 years, because they simply are so inefficient in the product development process. They are finding they do not have the money or engineers to expand their product range or renew their products frequently.

The lean supply chain

In mass production, the supply chain is price driven. The end cost of a vehicle is calculated by supply cost plus profit. A mass assembler will develop detailed drawings of components and put the parts out for bid. Suppliers tend to bid below cost in order to get the original contract, usually for only one year, with the understanding that once they are in place, it is highly unlikely that the assembler will drop their contract for someone else the second year into production. With the life of a vehicle being approximately 10 years, and with 10 more years of life in replacement parts, the supplier is quite willingly to take a loss the first year, with the promise of profits for the following 19 years, due to being able to raise prices every year. Assemblers are not even likely to balk at price increases over the years, because it is cheaper than finding a new supplier.

There are even additional profits to be made in the increased productivity a supplier will develop over the life of a component. As the learning curve increases, the cost of production decreases, adding to a supplier's profits.

The mass production chain also tends to include many more components for manufacture. Instead of contracting with one firm to make a whole seat, a mass assembler will contract with 25 different companies to make the 25 different components of a seat. Unfortunately, due to different contents of materials, etc. the parts never fit together exactly, or expand the same in hot and cold weather, thereby creating gaps, leaks and squeaks over the life of the car.

In the lean production supply chain, first tier suppliers are established over time, and long standing relationships are set with them. The design team for the assembler will assign whole components (i.e. seats, fuel injection systems) to one first tier supplier. There is no competition amongst suppliers based on bidding. The supplier has its own engineers that then work with engineers from the assembler's product design team to create a whole component system that works in harmony with the rest of the vehicle design. The first tier supplier then contracts second, third and even fourth tier suppliers to make the components and assemble them.

The lean assembler also establishes a target price for the vehicle from the beginning and works backwards figuring how the vehicle can be made for that price, while still allowing reasonable profit for both the assembler and the supplier. Where the mass production process creates tension between suppliers and assembler as to who can actually make any profit, the lean production system encourages them to work together to allow profit for both companies.

The lean production system also uses the just-in-time method of supply. Where mass production is at the mercy of highly cyclical production and relies on layoffs to manage the cycle in slow periods and large supplier inventory to handle it in swells, the just-in-time

method relies on empty parts boxes from the plant being returned to the supplier as the indicator of how many components to supply. The supplier tailors their manufacturing rate to that of the assembler, and makes products in small batches (due to the ease of change in machinery to make different parts), and can therefore manage product flow better than the large continuous batches that are made for years at a time in traditional mass production facilities.

The issue of quality of parts is addressed very differently also. In mass production, parts are inspected as they arrive at the assembly plant. Defective parts are thrown away or returned for credit. When the number of defective parts in a batch becomes too high, the entire batch is returned. In lean production, parts are not inspected at all when they arrive at the plant. They go right to the line. The lean supplier knows what defects can do - they will shut down the whole line - and therefore takes great pains not to let that happen. Again, it is an issue of working together as a team instead of working against each other, competing for profits. When defects are found, the assembler's quality control department rapidly goes through the "five why's" to determine the cause of the defect and to address the issue so that it never happens again. This information is shared with the supplier and the problem is corrected together, with the assembler's assistance if necessary.

The last major feature of lean supply is the supplier associations. Where mass suppliers compete against each other on price, and hold all information regarding price, profit and design as confidential and secret, lean suppliers meet regularly to share information about new ways they have discovered to make better parts. They understand that success for one supplier means success for the rest of them.

Conclusion

Lean production raises the threshold of acceptable quality to a level that mass production cannot easily match. It offers ever-expanding product variety and rapid responses to changing consumer tastes. It lowers the amount of high-wage effort needed to produce a product, and it keeps reducing it through continuous incremental improvement.

The Machine that Changed the World
by James P. Womack, Daniel T. Jones, and Daniel Roos
1990; Harper Perennial, 1991