THE STORY
OF LEAN
PRODUCTION—
TOYOTA'S
SECRET
WEAPON IN
THE GLOBAL
CAR WARS
THAT IS
REVOLUTIONIZING
WORLD
INDUSTRY

THE MACHINE THAT CHANGED THE WORLD

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Foreword 2007

Why Toyota Won: A Tale of Two Business Systems

In 1990, when *The Machine That Changed the World* was originally published, Toyota was half the size of General Motors and two-thirds the size of Ford. Today, as this book is reissued for a new generation of readers, Toyota has easily passed Ford and is surging past GM to become the largest and most consistently successful industrial enterprise in the world. This book tells why.

However, this is not simply the story of three giant firms in one giant industry. The great contribution of this volume—the reason it is as relevant today as when it was first published—is that it clearly describes two fundamentally different business systems, two ways of thinking about how humans work together to create value. One system—mass production—was pioneered by General Motors in the 1920s as it passed Ford to become the world's largest industrial enterprise. This system was then widely copied and used by enterprises in practically every industry all over the globe—including Ford and General Electric—for nearly seventy-five years. The other business system—lean production—was pioneered by Toyota in the twenty years immediately after World War II and is now rapidly diffusing to every corner of the world.

In simplest terms, this book tells the story of mass versus lean and shows why lean is superior. It tells not only why Toyota won but how any organization embracing the complete system of lean production can also win.

To tell this story, the book provides a history and description of craft, mass, and lean production in the first three chapters and then describes the five elements of a lean business system in the next five chapters. These elements are designing the product, coordinating the supply chain, dealing with the customer, producing the product from order to delivery, and managing the combined enterprise. Every organization creating value for consumers—including service organizations such as healthcare—must tackle these five tasks. So the lessons of the lean production system, combining all five elements in a mutually supportive way, have remarkably broad application. The "machine" that is changing the world is this complete lean business system, whose initial diffusion across the world is described in the three final chapters.

After nearly two decades in the market, it seems fair to say that *Machine* has now become a management classic. It is the third book in a historical sequence beginning with Peter Drucker's *Concept of the Corporation* (1946), which first summarized the mass production business model, and continuing with Alfred Sloan's *My Years with General Motors* (1965), in which the chief architect of this system explained it in very precise detail.

Given that *Machine* has become a historical artifact, it has not seemed appropriate to modify the text in light of what has happened and what has been learned in the years since its original publication. Thus the material between this Foreword and a new Afterword is exactly as it was in the original except for the correction of a few typographical and factual errors. However, in the Afterword we have added considerable additional material describing what the authors have learned about lean production since *Machine* was published.

By bringing the story up to date, we believe that we will enable today's readers to continue to draw valuable lessons from this volume. *Machine* describes a world-changing transformation in management thinking, relevant to everyone's organization as we all seek to become lean producers.

DAN JONES, GOODRICH, HEREFORD, UK
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THE MACHINE THAT CHANGED THE WORLD

BEFORE YOU BEGIN THIS BOOK

On a sunny afternoon in the fall of 1984, we stood on the granite front steps of the Massachusetts Institute of Technology and pondered the future. We had just concluded an international conference to announce the publication of our previous book, *The Future of the Automobile,*[1] in which we examined the problems facing the world motor-vehicle industry at that time.

Our findings about the automobile itself were guardedly optimistic. We concluded that technical means were on hand to solve the most pressing environmental and energy problems caused by the use of cars and trucks. There were still question marks about the long term, in particular about the "greenhouse" effect caused in part by carbon dioxide spewing from auto tailpipes, but we thought the automobile itself could adapt. However, we were much gloomier about the auto industry and the world economy.

We concluded that the auto industries of North America and Europe were relying on techniques little changed from Henry Ford's mass-production system and that these techniques were simply not competitive with a new set of ideas pioneered by the Japanese companies, methods for which we did not even have a name. As the Japanese companies gained market share, they were encountering more and more political resistance. At the same time, the Western companies didn't seem to be able to learn from their Japanese competitors. Instead, they were focusing their energies on erecting trade barriers and other competitive impediments, which we thought simply delayed dealing with the real issue. When the next economic downturn came, we feared that North America and Europe would seal themselves off from the Japanese threat and, in the process, reject the opportunity for the prosperity and more rewarding work that these new techniques offer.

We felt that the most constructive step we could take to prevent this development from occurring would be to undertake a detailed study of the new Japanese techniques, which we subsequently named "lean production," compared with the older Western mass-production techniques, and to do so in partnership with all the world's motor-vehicle manufacturers. But how? As we were pondering this question on that sunny afternoon, one of the senior industry executives attending our conference approached us . . . with precisely this idea.

"Why not also include governments worried about revitalizing their motor-vehicle industries," he asked, "and raise enough funds to really do the job properly?" Thus was born the International Motor Vehicle Program (IMVP) at Massachusetts Institute of Technology and, ultimately, this book.

THE INTERNATIONAL MOTOR VEHICLE PROGRAM

At the beginning of 1985, a fortuitous event at MIT provided the ideal institutional setting for the IMVP. A new Center for Technology, Policy and Industrial Development was formed with Daniel Roos as its first director. 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 IMVP was an ideal program for the new Center to demonstrate a creative role for a university in working cooperatively with governments and industry.

As we moved ahead with planning the IMVP in the new Center, we realized that our success would depend critically on six elements: thoroughness, expertise, a global outlook, independence, industry access, and continuous feedback.

First, we had to examine the *entire* set of tasks necessary to manufacture a car or truck: market assessment, product design, detailed engineering, coordination of the supply chain, operation of individual factories, and sales and service of the finished product. We knew that many efforts to understand this industry had failed because they never looked further than the factory, an important element in the system to be sure, but only a small part of the total.

We realized that to do a thorough job we would need many types of expertise of a sort not normally found in a university setting. We would need researchers knowledgeable about each aspect of the system who were committed to rigorous research methods, but who were also comfortable with the inherent messiness of the industrial world, where nothing is ever as neat as in academic models. Our solution was to find researchers now in academia who had come from the world of industry and who were willing to go back into design shops, supply companies, and factories for weeks or months to gather the detailed information we needed for sound conclusions.

For example, Richard Lamming and Toshihiro Nishiguchi, our specialists in supply systems, were pursuing Ph.D.'s in England at the University of Sussex and Oxford University, respectively, during their tenure with the IMVP. However, their interest in supply came from their previous work experience in Western and Japanese companies. Richard had been a parts buyer for Jaguar in England, while Toshihiro had worked for Pioneer Electric in Japan. During their four years of work for the IMVP they visited hundreds of component supply companies and plants in North America, Western Europe, and Japan. In addition, they examined supply systems in the leading developing countries, including Korea, Taiwan, and Mexico.

Similarly, Andrew Graves, our technology specialist, was pursuing a Ph.D. at the University of Sussex after many years in a career as a builder of Formula 1 racing cars. Andy spent months traveling to the major design and engineering centers of the motor-vehicle world. On each visit he was testing ideas about the best means for companies to introduce new technologies, ideas formed initially in the world of auto racing, where continuous technical leadership is the key to success.

One of our factory specialists, John Krafcik, was the first American engineer hired at the Toyota–General Motors joint venture, NUMMI. His training at NUMMI included lengthy periods in Japan at Toyota factories in Toyota City, where he learned the fundamentals of lean production at the source. John completed an MBA degree at MIT's Sloan School of Management while traveling the world surveying ninety auto assembly plants in fifteen countries, in what we believe is the most comprehensive industrial survey ever undertaken in any industry.

Two additional MBA students at MIT, Antony Sheriff and Kentaro Nobeoka, provided insight for our product-development studies, through case studies of the product-development process based on their previous work as product planners at Chrysler and Mazda, respectively.

A mere listing of these names shows an additional feature of our work that we felt was essential—to develop a completely international team of researchers, with the language and cultural skills to understand production methods in different countries and an eagerness to explain their findings to colleagues from very different backgrounds. These researchers (who are listed in Appendix B) were not primarily stationed at MIT and were not primarily American. Rather, we developed a worldwide team with no geographic center and no one nationality in the majority.

To be taken seriously both inside and outside the motor-vehicle industry we needed to be independent. Therefore, we determined to raise the $5 million we needed through contributions from many car companies, components suppliers, and governments. (The thirty-six organizations ultimately contributing to the IMVP are listed in Appendix A.) We limited contributions from individual companies and governments to 5 percent of the $5 million total and placed all the funds in a single account, so that no sponsor could influence the direction of our work by earmarking its contribution for a special purpose. We were also careful to raise funds in equal amounts in North America, Western Europe, and Japan, so that we would not be subject to national or regional pressures in our conclusions.

For our researchers to succeed, they would need extensive access to motor-vehicle companies across the world, from the factory floor to the executive suite. We therefore made it clear to potential sponsors that their most valuable contribution would not be money but rather the time given by their employees to answer our questions. In every case these companies have been even more open than we had hoped. We have been truly amazed by the spirit of professionalism in this industry, which has 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.

Finally, to succeed in our work we were determined to devise a set of feedback mechanisms where we could explain our findings to industry, governments, and unions and gain their reactions for our mutual benefit. We did this in three ways.

First, we held an annual meeting for the liaison person from each sponsor. At these meetings we went over the previous year's research in detail, asking for criticism and for suggestions about the next steps for our research.

Second, we held an annual policy forum at a different location around the world—Niagara-on-the-Lake in Canada, Como in Italy, Acapulco in Mexico—to present our findings to senior executives and government officials from the sponsoring companies and governments, plus interested observers from labor unions and the financial community. These private meetings provided an opportunity for senior leaders of this industry to discuss the real problems of moving the world from mass to lean production, outside the glare of publicity and the need for public posturing. (Those attending the IMVP policy forums are listed in Appendix C.)

Finally, we've conducted several hundred private briefings for companies, governments, and unions. For example, our factory practice team conducted a seminar at each of the ninety assembly plants we visited as part of the IMVP World Assembly Plant Survey. In these seminars, we reviewed worldwide performance, assessed the performance of the plant we were visiting, and explained the reasons that plant might lag in world-class performance. We also conducted briefings for corporate management boards, union executive committees, government ministries, and leaders in the investment community, in each case explaining the differences between mass production and lean with ideas on how to convert to lean production.

THIS BOOK

We have now spent five years exploring the differences between mass production and lean production in one enormous industry. We have been both insiders with access to vast amounts of proprietary information and daily contact with industry leaders, and outsiders with a broad perspective, often very critical, on existing practices. In this process we've become convinced 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.

We therefore decided not to write an academic report on our work, a dry summary of findings by a committee seeking a consensus. Instead, in the pages that follow, the three of us, as leaders of the Program, tell the story of how human society went about making things during the rise, and now the decline of the age of mass production, and how some companies in some countries have pioneered a new way of making things in the dawning age of lean production. In the last part of our book, we provide a vision of how the whole world can enter this new age.

Our story draws on the 116 research monographs prepared by IMVP Research Affiliates, as listed in Appendix D, but necessarily provides only a small fraction of the evidence behind our analysis. Readers with further interest in specific topics should consult Appendix D and write for copies to the IMVP, Center for Technology, Policy and Industrial Development, E40-219, MIT, Cambridge, MA 02139 U.S.A.

Readers should realize that with such a rich diversity of global intellectual resources and viewpoints, IMVP researchers have not agreed on every point. This volume presents the personal view of the three Program leaders and should not be taken as an official statement agreed to by all participants. Certainly, they should not be blamed for any errors or omissions.

Our story is not just for an industry audience but for everyone—government officials, labor leaders, industry executives, and general readers—in every country with an interest in how society goes about making things. In the process, we necessarily make some unflattering comparisons of companies and countries. We ask the reader to take these in the proper spirit. We have no wish to embarrass, or for that matter to compliment, but rather to illustrate the transition from mass to lean production with concrete examples that readers can understand.

We also ask the reader to understand that our sponsors have been extraordinarily supportive of our work. They have sent senior executives to our annual meetings and several have given us a critique of a draft of this volume—in some cases voicing disagreements. However, they have neither exercised veto power over our findings nor endorsed our conclusions. The views in the pages ahead are strictly our own. For our sponsors' willingness to let us think big thoughts without interference at a time of profound transition, we are deeply grateful.

A FINAL CHALLENGE FOR THE READER

In presenting our work to a broad audience we have one great fear: that readers will praise it or condemn it as yet another "Japan" book, concerned with how a subset of the population within a relatively small country produces manufactured goods in a unique way. Our intention is emphatically different. We believe that the fundamental ideas of lean production are universal—applicable anywhere by anyone—and that many non-Japanese companies have already learned this.

Thus we devote our attention in the pages ahead to a careful explanation of the logic and techniques of lean production. We pay little attention to the special features of Japanese society—the high savings rate, near universal literacy, a homogeneous population, the often alleged inclination to subordinate personal desires to group needs, and the willingness, even the desire, to work long hours—which some observers credit for Japanese success, but which we believe are of secondary importance.

Similarly, we pay little attention to other features of Japanese society—the limited role for women and minorities in the economy, the tight relation between government and industry, the barriers to foreign penetration of the domestic market, and the pervasive distinction between foreign and Japanese—which other countries adopting lean production would neither want nor need to copy. This is not a book about what is wrong with Japan or with the rest of the world but about what is right with lean production.

Nevertheless, the level of tension about trade and investment between Japan and the rest of the world is now so great that most readers, in Japan as well as the West, will need to make a special effort to extract the universal principles of lean production from their initial, Japanese application.

Early in this century, most Europeans were unable to differentiate the universal ideas and advantages of mass production from their unique American origins. As a result, ideas of great benefit were rejected for a generation. The great challenge of the current moment is to avoid making such an error twice.

1 THE INDUSTRY OF INDUSTRIES IN TRANSITION

Forty years ago Peter Drucker dubbed it "the industry of industries."[1] Today, automobile manufacturing is still the world's largest manufacturing activity, with nearly 50 million new vehicles produced each year.

Most of us own one, many of us own several, and, although we may be unaware of it, these cars and trucks are an important part of our everyday lives.

Yet the auto industry is even more important to us than it appears. Twice in this century it has changed our most fundamental ideas of how we make things. And how we make things dictates not only how we work but what we buy, how we think, and the way we live.

After World War I, Henry Ford and General Motors' Alfred Sloan moved world manufacture from centuries of craft production—led by European firms—into the age of mass production. Largely as a result, the United States soon dominated the global economy.

After World War II, Eiji Toyoda and Taiichi Ohno at the Toyota Motor Company in Japan pioneered the concept of lean production. The rise of Japan to its current economic preeminence quickly followed, as other Japanese companies and industries copied this remarkable system.

Manufacturers around the world are now trying to embrace lean production, but they're finding the going rough. The companies that first mastered this system were all headquartered in one country—Japan. As lean production has spread to North America and Western Europe under their aegis, trade wars and growing resistance to foreign investment have followed.

Today, we hear constantly that the world faces a massive overcapacity crisis—estimated by some industry executives at more than 8 million units in excess of current world sales of about 50 million units.[2] This is, in fact, a misnomer. The world has an acute shortage of competitive lean-production capacity and a vast glut of uncompetitive mass-production capacity. The crisis is caused by the former threatening the latter.

Many Western companies now understand lean production, and at least one is well along the path to introducing it. However, superimposing lean-production methods on existing mass-production systems causes great pain and dislocation. In the absence of a crisis threatening the very survival of the company, only limited progress seems to be possible.

General Motors is the most striking example. This gigantic company is still the world's largest industrial concern and was without doubt the best at mass production, a system it helped to create. Now, in the age of lean production, it finds itself with too many managers, too many workers, and too many plants. Yet GM has not yet faced a life-or-death crisis, as the Ford Motor Company did in the early 1980s, and thus it has not been able to change.[3]

This book is an effort to ease the necessary transition from mass production to lean. By focusing on the global auto industry, we explain in simple, concrete terms what lean production is, where it came from, how it really works, and how it can spread to all corners of the globe for everyone's mutual benefit.

But why should we care if world manufacturers jettison decades of mass production to embrace lean production? Because the adoption of lean production, as it inevitably spreads beyond the auto industry, will change everything in almost every industry—choices for consumers, the nature of work, the fortune of companies, and, ultimately, the fate of nations.

What is lean production? Perhaps the best way to describe this innovative production system is to contrast it with craft production and mass production, the two other methods humans have devised to make things.

The craft producer uses highly skilled workers and simple but flexible tools to make exactly what the consumer asks for—one item at a time. Custom furniture, works of decorative art, and a few exotic sports cars provide current-day examples. We all love the idea of craft production, but the problem with it is obvious: Goods produced by the craft method—as automobiles once were exclusively—cost too much for most of us to afford. So mass production was developed at the beginning of the twentieth century as an alternative.

The mass producer uses narrowly skilled professionals to design products made by unskilled or semiskilled workers tending expensive, single-purpose machines. These churn out standardized products in very high volume. Because the machinery costs so much and is so intolerant of disruption, the mass producer adds many buffers—extra supplies, extra workers, and extra space—to assure smooth production. Because changing over to a new product costs even more, the mass producer keeps standard designs in production for as long as possible. The result: The consumer gets lower costs but at the expense of variety and by means of work methods that most employees find boring and dispiriting.

The lean producer, by contrast, combines the advantages of craft and mass production, while avoiding the high cost of the former and the rigidity of the latter. Toward this end, lean producers employ teams of multiskilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in enormous variety.

Lean production (a term coined by IMVP researcher John Krafcik) is "lean" because it uses less of everything compared with 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 in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products.

Perhaps the most striking difference between mass production and lean production lies in their ultimate objectives. Mass producers set a limited goal for themselves—"good enough," which translates into an acceptable number of defects, a maximum acceptable level of inventories, a narrow range of standardized products. To do better, they argue, would cost too much or exceed inherent human capabilities.

Lean producers, on the other hand, set their sights explicitly on perfection: continually declining costs, zero defects, zero inventories, and endless product variety. Of course, no lean producer has ever reached this promised land—and perhaps none ever will, but the endless quest for perfection continues to generate surprising twists.

For one, lean production changes how people work but not always in the way we think. Most people—including so-called blue-collar workers—will find their jobs more challenging as lean production spreads. And they will certainly become more productive. At the same time, they may find their work more stressful, because a key objective of lean production is to push responsibility far down the organizational ladder. Responsibility means freedom to control one's work—a big plus—but it also raises anxiety about making costly mistakes.

Similarly, lean production changes the meaning of professional careers. In the West, we are accustomed to think of careers as a continual progression to ever higher levels of technical know-how and proficiency in an ever narrower area of specialization as well as responsibility for ever larger numbers of subordinates—director of accounting, chief production engineer, and so on.

Lean production calls for learning far more professional skills and applying these creatively in a team setting rather than in a rigid hierarchy. The paradox is that the better you are at teamwork, the less you may know about a specific, narrow specialty that you can take with you to another company or to start a new business. What's more, many employees may find the lack of a steep career ladder with ever more elaborate titles and job descriptions both disappointing and disconcerting.

If employees are to prosper in this environment, companies must offer them a continuing variety of challenges. That way, they will feel they are honing their skills and are valued for the many kinds of expertise they have attained. Without these continual challenges, workers may feel they have reached a dead end at an early point in their career. The result: They hold back their know-how and commitment, and the main advantage of lean production disappears.

This sketch of lean production and its effects is highly simplified, of course. Where did this new idea come from and precisely how does it work in practice? Why will it result in such profound political and economic changes throughout the world? In this book we provide the answers.

In "The Origins of Lean Production," we trace the evolution of lean production. We then look in "The Elements of Lean Production" at how lean production works in factory operations, product development, supply-system coordination, customer relations, and as a total lean enterprise.

Finally, in "Diffusing Lean Production," we examine how lean production is spreading across the world and to other industries and, in the process, is revolutionizing how we live and work. As we'll also see, however, lean production isn't spreading everywhere at a uniform rate. So we'll look at the barriers that are preventing companies and countries from becoming lean. And we'll suggest creative ways leanness can be achieved.

THE ORIGINS OF LEAN PRODUCTION

No new idea springs full-blown from a void. Rather, new ideas emerge from a set of conditions in which old ideas no longer seem to work. This was certainly true of lean production, which arose in one country at a specific time because conventional ideas for the industrial development of the country seemed unworkable. Therefore, to understand lean production and its origins fully, it is important to go much further back in time, in fact, back to the origins of the motor industry at the end of the nineteenth century.

In Chapter 2, we look at the craft origins of the industry in the 1880s and the transition to mass production around 1915, when craft production encountered problems it could not surmount. We take pains to describe the mature system of mass production as it came to exist by the 1920s, including its strengths and weaknesses, because the system's weaknesses eventually became the source of inspiration for the next advance in industrial thinking.

In Chapter 3, we are then ready to examine the genesis of lean production in the 1950s and how it took root. We also summarize the key features of the fully developed lean-production system as it came to exist in Japan by the 1960s, at a point long before the rest of the world took note.

2 THE RISE AND FALL OF MASS PRODUCTION

In 1894, the Honorable Evelyn Henry Ellis, a wealthy member of the English Parliament, set out to buy a car.[1] He didn't go to a car dealer—there weren't any. Nor did he contact an English automobile manufacturer—there weren't any of those either.

Instead, he visited the noted Paris machine-tool company of Panhard et Levassor and commissioned an automobile. Today, P&L, as it was known, is remembered only by classic-car collectors and auto history buffs, but, in 1894, it was the world's leading car company.[2]

It got its start—and a jump on other potential competitors—when in 1887 Emile Levassor, the "L" of P&L, met Gottlieb Daimler, the founder of the company that today builds the Mercedes-Benz. Levassor negotiated a license to manufacture Daimler's new "high-speed" gasoline engine.

By the early 1890s, P&L was building several hundred automobiles a year. The cars were designed according to the *Système Panhard*—meaning the engine was in the front, with passengers seated in rows behind, and the motor drove the rear wheels.

When Ellis arrived at P&L, which was still primarily a manufacturer of metal-cutting saws rather than automobiles, he found in place the classic craft-production system. P&L's workforce was overwhelmingly composed of skilled craftspeople who carefully hand-built cars in small numbers.

These workers thoroughly understood mechanical design principles and the materials with which they worked. What's more, many were their own bosses, often serving as independent contractors within the P&L plant or, more frequently, as independent machine-shop owners with whom the company contracted for specific parts or components.

The two company founders, Panhard and Levassor, and their immediate associates were responsible for talking to customers to determine the vehicle's exact specifications, ordering the necessary parts, and assembling the final product. Much of the work, though, including design and engineering, took place in individual craft shops scattered throughout Paris.

One of our most basic assumptions in the age of mass production—that cost per unit falls dramatically as production volume increases—was simply not true for craft-based P&L. If the company had tried to make 200,000 identical cars each year, the cost per car probably wouldn't have dipped much below the cost per car of making ten.

What's more, P&L could never have made two—much less 200,000—identical cars, even if these were built to the same blueprints. The reasons? P&L contractors didn't use a standard gauging system, and the machine tools of the 1890s couldn't cut hardened steel.

Instead, different contractors, using slightly different gauges, made the parts. They then ran the parts through an oven to harden their surfaces enough to withstand heavy use. However, the parts frequently warped in the oven and needed further machining to regain their original shape.

When these parts eventually arrived at P&L's final assembly hall, their specifications could best be described as approximate. The job of the skilled fitters in the hall was to take the first two parts and file them down until they fit together perfectly.

Then they filed the third part until it fit the first two, and so on until the whole vehicle—with its hundreds of parts—was complete.

This sequential fitting produced what we today call "dimensional creep." So, by the time the fitters reached the last part, the total vehicle could differ significantly in dimensions from the car on the next stand that was being built to the same blueprints.

Because P&L couldn't mass-produce identical cars, it didn't try. Instead, it concentrated on tailoring each product to the precise desires of individual buyers.

It also emphasized its cars' performance and their hand-fitted craftsmanship in which the gaps between individual parts were nearly invisible.

To the consumers Panhard was trying to woo, this pitch made perfect sense. These wealthy customers employed chauffeurs and mechanics on their personal staffs. Cost, driving ease, and simple maintenance weren't their primary concerns. Speed and customization were.

Evelyn Ellis was no doubt typical of P&L's clients. He didn't want just any car; he wanted a car built to suit his precise needs and tastes. He was willing to accept P&L's basic chassis and engine, he told the firm's owners, but he wanted a special body constructed by a Paris coachbuilder.

He also made a request to Levassor that would strike today's auto manufacturer as preposterous: He asked that the transmission, brake, and engine controls be transferred from the right to the left side of the car. (His reason wasn't that the English drove on the left—in that case, moving the controls to the left side of the vehicle was precisely the wrong thing to do. Besides, the steering tiller remained in the middle. Rather, he presumably thought the controls were more comfortable to use in that position.)

For P&L, Ellis's request probably seemed simple and reasonable. Since each part was made one at a time, it was a simple matter to bend control rods to the left rather than the right and to reverse the linkages. For today's mass producer, this modification would require years—and millions or hundreds of millions of dollars—to engineer. (American companies still offer no right-side-drive option on cars they sell in drive-on-the-left Japan, since they believe the cost of engineering the option would be prohibitive.)

Once his automobile was finished, Ellis, accompanied by a mechanic engaged for the purpose, tested it extensively on the Paris streets. For, unlike today's cars, the vehicle he had just bought was in every sense a prototype. When he was satisfied that his new car operated properly—quite likely after many trips back to the P&L factory for adjustment—Ellis set off for England.

His arrival in June 1895 made history. Ellis became the first person to drive an automobile in England. He traversed the fifty-six miles from Southampton to his country home in a mere 5 hours and 32 minutes—exclusive of stops—for an average speed of 9.84 miles per hour. This speed was, in fact, flagrantly illegal, since the limit in England for non-horse-drawn vehicles was a sedate 4 miles per hour. But Ellis didn't intend to remain a lawbreaker.

By 1896, he had taken the Parliamentary lead in repealing the "flag law" that limited automotive speeds, and had organized an Emancipation Run from London to Brighton, a trip on which some cars even exceeded the new legal speed limit of 12 miles per hour. Around this time, a number of English firms began to build cars, signaling that the automotive age was spreading from its origins in France to England in its march across the world.

Evelyn Ellis and P&L are worth remembering, despite the subsequent failure of the Panhard firm and the crudeness of Ellis's 1894 auto (which found a home in the Science Museum in London, where you can see it today). Together, they perfectly summarize the age of craft production in the motor industry.

In sum, craft production had the following characteristics:

- A workforce that was highly skilled in design, machine operations, and fitting. Most workers progressed through an apprenticeship to a full set of craft skills. Many could hope to run their own machine shops, becoming self-employed contractors to assembler firms.
- Organizations that were extremely decentralized, although concentrated within a single city. Most parts and much of the vehicle's design came from small machine shops. The system was coordinated by an owner/entrepreneur in direct contact with everyone involved—customers, employers, and suppliers.
- The use of general-purpose machine tools to perform drilling, grinding, and other operations on metal and wood.
- A very low production volume—1,000 or fewer automobiles a year, only a few of which (fifty or fewer) were built to the same design. And even among those fifty, no two were exactly alike since craft techniques inherently produced variations.

No company, of course, could exercise a monopoly over these resources and characteristics, and Panhard et Levassor was soon competing with scores of other companies, all producing vehicles in a similar manner. By 1905, less than twenty years after P&L produced the first commercially successful automobile, hundreds of companies in Western Europe and North America were turning out autos in small volumes using craft techniques.

The auto industry progressed to mass production after World War I, and P&L eventually foundered trying to make the conversion. Yet, a number of craft-production firms have survived up to the present. They continue to focus on tiny niches around the upper, luxury end of the market, populated with buyers wanting a unique image and the opportunity to deal directly with the factory in ordering their vehicles.

Aston Martin, for example, has produced fewer than 10,000 cars at its English workshop over the past sixty-five years and currently turns out only one automobile each working day. It survives by remaining small and exclusive, making a virtue of the high prices its craft-production techniques require. In its body shop, for example, skilled panel beaters make the aluminum body panels by pounding sheets of aluminum with wooden mallets.

In the 1980s, as the pace of technological advances in the auto industry has quickened, Aston Martin and similar firms have had to ally themselves with the automotive giants (Ford, in Aston Martin's case[3]) in order to gain specialized expertise in areas ranging from emission controls to crash safety. The cost of their developing this expertise independently would have been simply prohibitive.

In the 1990s, yet another threat will emerge for these craft firms as companies mastering lean production—led by the Japanese—begin to pursue their market niches, which were too small and specialized for the mass producers, such as Ford and GM, ever to have successfully attacked. For example, Honda has just introduced its aluminum-bodied NS-X sports car, which is a direct attack on Ferrari's niche in ultra-high-performance sports cars. If these lean-production firms can cut design and manufacturing costs and improve on the product quality offered by the craft firms—and they probably can—the traditional craft producers will either have to adopt lean-production methods themselves or perish as a species after more than a century.

Nostalgists see Panhard and its competitors as the golden age of auto production: Craftsmanship counted and companies gave their full attention to individual consumers. Moreover, proud craft workers honed their skills and many became independent shop owners.

That's all true, but the drawbacks of craft production are equally obvious in hindsight. Production costs were high and didn't drop with volume, which meant that only the rich could afford cars. In addition, because each car produced was, in effect, a prototype, consistency and reliability were elusive. (This, by the way, is the same problem that plagues satellites and the U.S. space shuttle, today's most prominent craft products.)

Car owners like Evelyn Ellis, or their chauffeurs and mechanics, had to provide their own on-the-road testing. In other words, the system failed to provide product quality—in the form of reliability and durability rather than lots of leather or walnut—because of the lack of systematic testing.

Also fatal to the age, however, was the inability of the small independent shops, where most of the production work took place, to develop new technologies. Individual craftsmen simply did not have the resources to pursue fundamental innovations; real technological advance would have required systematic research rather than just tinkering. Add these limitations together and it is clear, in retrospect, that the industry was reaching a plateau when Henry Ford came along. That is, as the general design of cars and trucks began to converge on the now familiar four-wheel, front-engine, internal-combustion vehicle we know today, the industry reached a premature maturity, fertile ground for a new production idea.

At this point, Henry Ford found a way to overcome the problems inherent in craft production. Ford's new techniques would reduce costs dramatically while increasing product quality. Ford called his innovative system *mass production*.[4]

MASS PRODUCTION

Ford's 1908 Model T was his twentieth design over a five-year period that began with the production of the original Model A in 1903. With his Model T, Ford finally achieved two objectives. He had a car that was designed for manufacture, as we would say today, and that was, also in today's terms, user-friendly. Almost anyone could drive and repair the car without a chauffeur or mechanic. These two achievements laid the groundwork for the revolutionary change in direction for the entire motor-vehicle industry.[5]

The key to mass production wasn't—as many people then and now believe—the moving, or continuous, assembly line. *Rather, it* *was the complete and consistent interchangeability of parts and the simplicity of attaching them to each other.* These were the manufacturing innovations that made the assembly line possible.

To achieve interchangeability, Ford insisted that the same gauging system be used for every part all the way through the entire manufacturing process. His insistence on working-to-gauge throughout was driven by his realization of the payoff he would get in the form of savings on assembly costs. Remarkably, no one else in the fledgling industry had figured out this cause-and-effect; so no one else pursued working-to-gauge with Ford's near-religious zeal.

Ford also benefitted from recent advances in machine tools able to work on *prehardened* metals. The warping that occurred as machined parts were being hardened had been the bane of previous attempts to standardize parts. Once the warping problem was solved, Ford was able to develop innovative designs that reduced the number of parts needed and made these parts easy to attach. For example, Ford's four-cylinder engine block consisted of a single, complex casting. Competitors cast each cylinder separately and bolted the four together.

Taken together, interchangeability, simplicity, and ease of attachment gave Ford tremendous advantages over his competition. For one, he could eliminate the skilled fitters who had always formed the bulk of every assembler's labor force.

Ford's first efforts to assemble his cars, beginning in 1903, involved setting up assembly stands on which a whole car was built, often by one fitter. In 1908, on the eve of the introduction of the Model T, a Ford assembler's average task cycle—the amount of time he worked before repeating the same operations—totaled 514 minutes, or 8.56 hours. Each worker would assemble a large part of a car before moving on to the next. For example, a worker might put all the mechanical parts—wheels, springs, motor, transmission, generator—on the chassis, a set of activities that took a whole day to complete. The assembler/fitters performed the same set of activities over and over at their stationary assembly stands. They had to get the necessary parts, file them down so they would fit (Ford hadn't yet achieved perfect interchangeability of parts), then bolt them in place.

The first step Ford took to make this process more efficient was to deliver the parts to each work station. Now the assemblers could remain at the same spot all day.

Then, around 1908, when Ford finally achieved perfect part