

The genealogy of lean production

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Abstract

Lean production not only successfully challenged the accepted mass production practices in the automotive industry, significantly shifting the trade-off between productivity and quality, but it also led to a rethinking of a wide range of manufacturing and service operations beyond the high-volume repetitive manufacturing environment. The book ‘The machine that changed the World’ that introduced the term ‘lean production’ in 1990 has become one of the most widely cited references in operations management over the last decade. Despite the fact that the just-in-time (JIT) manufacturing concept had been known for almost a decade prior, the book played a key role in disseminating the concept outside of Japan. While the technical aspects of lean production have been widely discussed, this paper sets out to investigate the evolution of the research at the MIT International Motor Vehicle Program (IMVP) that led to the conception of the term ‘lean production’. Furthermore, the paper investigates why – despite the pre-existing knowledge of JIT – the program was so influential in promoting the lean production concept. Based on iterating series of interviews with the key authors, contributors and researchers of the time, this paper presents an historical account of the research that led to the formulation and dissemination of one of the most influential manufacturing paradigms of recent times. © 2006 Elsevier B.V. All rights reserved.

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1. Thrust and motivation for this study

The initial stimulus for undertaking a study into the history of lean production was personal interest: having joined the International Motor Vehicle Program (IMVP) at MIT as a Sloan Industry Center Fellow in 2002, I was well aware of the long history and the impact the program had through its publication of ‘The Machine that Changed the World’ (Womack et al., 1990). At the time the program had been running for almost a quarter of a century, and it soon transpired that – while the ‘Machine’ book was one of the most cited works in Operations Management (Lewis and Slack, 2003) – surprisingly little documentation was available with regards to the development of the

assembly plant methodology and other key contributions that laid the foundation for the book, other than in anecdotal form. A second motivation for the underlying study came from my graduate students posing the simple yet logical question as to why the book by Womack et al. in 1990 had been so influential, given that major studies on just-in-time (JIT) manufacturing and the Toyota Production System (TPS) had been published by Schonberger, Hall, and Monden almost a decade earlier (cf. Schonberger, 1982a; cf. Hall, 1983a; Monden, 1983). As I could not provide a satisfactory answer to this legitimate question, I set out to inquire.

In a first step, I questioned the IMVP researchers who contributed to the ‘discovery’ of the lean production paradigm from 1979 onwards. These interviews soon highlighted a fascinating story on the organisational settings and occurrences that in retrospect might seem like logical occurrences, but in fact

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were often merely fortunate coincidences. For example, the role of the Japanese transplant operations in shaping the research agenda has been widely understated in my view. In a second stage, in order to provide a more balanced perspective, I put the same question to early writers on just-in-time manufacturing and the Toyota Production System, namely Richard Schonberger, Robert ‘Doc’ Hall, Yasuhiro Monden, John Bicheno and Nick Oliver. The idea was to triangulate the previous account with a less MIT-centric view of the events at the time, and to complement the historic accounts given by the IMVP researchers (selected quotes from these interviews will be presented throughout this paper, marked with an asterisk *). In addition, I consulted Takahiro Fujimoto, Koichi Shimokawa and Kazuo Wada on the evolution of production systems in Japan in order to give an accurate account of the early documents on TPS and JIT, and their availability outside Toyota. Additional secondary material was sought from the archives at the Toyota Automobile Museum and the Imperial War Museum at Duxford. Finally, I reviewed the unpublished dissertations and working papers of the IMVP researchers in order to document the evolution of thought and methodology over time.

The paper is structured as follows: in Section 2, the evolution of the Toyota Production System and its formal documentation is briefly reviewed to set the wider context, Section 3 describes the establishment of the International Motor Vehicle Program, and Section 4 reviews the development of the assembly plant benchmarking methodology that provided the basis for the ‘Machine that Changed the World’. Section 5 discusses the complementing role of the U.S. transplant operations in the knowledge transfer from Japan to the Western world, before discussing the reasons behind the ‘Machine’ book’s success by opposing the authors’ and external experts’ views. Section 7 briefly outlines the research at IMVP after 1990, before concluding in Section 8.

2. A brief history of time: the Toyota Production System

The evolution of production systems in the motor industry has been comprehensively covered (Hounshell, 1984; Boyer et al., 1998), as has the story of the Toyota Production System, which fuelled one of the greatest corporate success stories (Cusumano, 1985; Ohno, 1988; Fujimoto, 1999). Of interest for this study is determined at which point the production system was formally documented in the public domain, or in other words, at what point could the outside world have taken notice of the developments at Toyota.

The foundation of the Toyota Motor Company dates back to 1918, when the entrepreneur Sakichi Toyoda established his spinning and weaving business based on his advanced automatic loom. He sold the patents to the Platts Brothers in 1929 for £100,000, and it is said that these funds provided the foundation for his son, Kiichiro, to realize his vision of manufacturing automobiles. While Wada’s recent analysis casts some doubt over its historical accuracy (Wada, 2004), the romantic version is that Sakichi told his son on his deathbed: ‘I served our country with the loom. I want you to serve it with the automobile’ (Ohno, 1988 p. 79). At the time the Japanese market was dominated by the local subsidiaries of Ford and General Motors (GM) which had been established in the 1920s, and starting Toyoda’s automotive business was fraught with financial difficulties and ownership struggles after Sakichi’s death in 1930. Nevertheless, Kiichiro prevailed – helped by the newly released Japanese automotive manufacturing law in 1930 – and began designing his Model AA by making considerable use of Ford and GM components (Cusumano, 1985). The company was relabelled ‘Toyota’ to simplify the pronunciation and give it an auspicious meaning in Japanese. Truck and car production started in 1935 and 1936, respectively, and in 1937 the Toyota Motor Company was formally formed. World War II disrupted production, and the post-war economic hardship resulted in growing inventories of unsold cars, leading to financial difficulties at Toyota. Resultant severe labour disputes in 1950 forced a split of the Toyota Motor Manufacturing and Toyota Motor Sales divisions, as well as the resignation of Kiichiro from the company.

His cousin Eiji Toyoda became managing director of the manufacturing arm and – in what in retrospect bears considerable irony – was sent to the United States in 1950 to study American manufacturing methods. Going abroad to study competitors was not unusual; pre-war a Toyota delegation had visited the Focke-Wulff aircraft works in Germany, where they observed the ‘Produktionstakt’ concept, which later developed into what we now know as ‘takt time’. Eiji Toyoda was determined to implement mass production techniques at Toyota, yet capital constraints and the low volumes in the Japanese market did not justify the large batch sizes common at Ford and GM. Toyota’s first plant in Kariya was thus used both for prototype development and production, and had a capacity of 150 units per month. The first high-volume car plant, Motomachi, was not opened until 1959.

While the simple and flexible equipment that Kiichiro had purchased in the 1930s would enable many of the concepts essential to TPS, the individual

that gave the crucial impulse towards developing the Toyota Production System capable of economically producing large variety in small volumes, was Taiichi Ohno (Āno Taiichi). Ohno had joined Toyoda Spinning and Weaving in 1932 after graduating as mechanical engineer, and only in 1943 joined the automotive business after the weaving and spinning business had been dissolved. Ohno did not have any experience in manufacturing automobiles, and it has been argued that his ‘common-sense approach’ without any preconceptions has been instrumental in developing the fundamentally different just-in-time philosophy (Cusumano, 1985). Analysing the Western production systems, he argued that they had two logical flaws. First, he reasoned that producing components in large batches resulted in large inventories, which took up costly capital and warehouse space and resulted in a high number of defects. The second flaw was the inability to accommodate consumer preferences for product diversity. Henry Ford himself learnt this lesson in the 1920s, when sales of the Model T dropped, as customers preferred buying second-hand Chevrolets, which offered choice in colour and optional equipment. It took Ford 1 year to introduce the Model A, while Alfred Sloan was introducing a product and brand portfolio at GM, offering ‘a car for every purse and purpose’ (Sloan, 1963; Hounshell, 1984). Ohno believed that GM had not abandoned Ford’s mass production system, since the objective was still to use standard components enabling large batch sizes, thus minimizing changeovers. In his view, the management of Western vehicle manufacturers were (and arguably still are) striving for large scale production and economies of scale, as outlined in the ‘Maxcy–Silberston curve’ (cf. Maxcy and Silberston, 1959).

From 1948 onwards, Ohno gradually extended his concept of small-lot production throughout Toyota from the engine machining shop he was managing (for a complete timeline see Ohno, 1988). His main focus was to reduce cost by eliminating waste, a notion that developed out of his experience with the automatic loom that stopped once the thread broke, in order not to waste any material or machine time. He referred to the loom as ‘a text book in front of my eyes’ (Cusumano, 1985), and this ‘jidoka’ or ‘autonomous machine’ concept would become an integral part of the Toyota Production System. Ohno also visited the U.S. automobile factories in 1956, and incorporated ideas he developed during these visits, most notably the ‘Kanban supermarket’ to control material replenishment. In his book, Ohno describes the two pillars of TPS as autonomation, based on Sakichi’s loom, and JIT, which he claims came from Kiichiro who once stated that ‘in a comprehensive

industry such as automobile manufacturing, the best way to work would be to have all the parts for assembly at the side of the line just in time for their user’ (Ohno, 1988, p. 75). In order for this system to work, it was necessary to produce and receive components and parts in small lot sizes, which was uneconomical according to traditional thinking. Ohno had to modify the machine changeover procedures to produce a growing variety in smaller lot sizes. This was helped by the fact that much of the machinery Kiichiro had bought was simple, general purpose equipment that was easy to modify and adapt. Change-over reduction was further advanced by Shigeo Shingo, who was hired as external consultant in 1955 and developed the single-minute exchange of dies (SMED) system (Shingo, 1983).

The result was an ability to produce a considerable variety of automobiles in comparatively low volumes at a competitive cost, altering the conventional logic of mass production. In retrospect these changes were revolutionary, yet these were largely necessary adaptations to the economic circumstances at the time (cf. Cusumano, 1985) that required low volumes and great variety. By 1950, the entire Japanese auto industry was producing an annual output equivalent to less than 3 days’ of the U.S. car production at the time. Toyota gradually found ways to combine the advantages of small-lot production with economies of scale in manufacturing and procurement, but counter to common perception, this implementation took considerable time. While one might be tempted to argue that Ohno had ‘invented’ a new production concept by 1948, it was in fact a continuously iterating learning cycle that spanned decades. Thus, more than anything, it is this ‘dynamic learning capability’ that is at the heart of the success of TPS. As Fujimoto concludes in his seminal review of the evolution of the Toyota Production System:

‘Toyota’s production organization [...] adopted various elements of the Ford system selectively and in unbundled forms, and hybridized them with their ingenious system and original ideas. It also learnt from experiences with other industries (e.g. textiles). It is thus a myth that the Toyota Production System was a pure invention of genius Japanese automobile practitioners. However, we should not underestimate the entrepreneurial imagination of Toyota’s production managers (e.g. Kiichiro Toyoda, Taiichi Ohno, and Eiji Toyoda), who integrated elements of the Ford system in a domestic environment quite different from that of the United States. Thus, the Toyota-style system has been neither purely original nor totally imitative. It is essentially a hybrid.’ (Fujimoto, 1999, p. 50).

Astonishingly, TPS was not formally documented until 1965 when Kanban systems were rolled out to the suppliers; there had simply not been a need to do so. As Robert Hall comments, ‘Toyota instructs implicitly. They cannot tell you in words what they are doing, not even in Japanese’*. As a result, the development of TPS was largely unnoticed – albeit not kept as a secret – and according to Ohno only started attracting attention during the first oil crisis in 1973. The oil crises also renewed the interest in researching the future of the automotive industry, the starting point of the International Motor Vehicle Program at MIT.

3. The inauguration of the International Motor Vehicle Program

The International Motor Vehicle Program began as a 5-year research program entitled ‘The Future of the Automobile’ in 1979 in the aftermath of the second oil crisis, with a small grant from the German Marshall Fund. Led by Dan Roos (the director of the Center for Transportation Studies) and Alan Altshuler (the head of the political science department at MIT at the time and who later joined Harvard) the program set out to research the role the automobile would take in the future. The programme was based at MIT, but from the start the idea was to create an international network of faculty at other universities. An early key contributor was Bill Abernathy at Harvard, who had a very active research interest in the automotive industry until he sadly lost his battle against cancer in 1983.

The main conclusion, published in the book entitled ‘The Future of the Automobile’ in 1984 (Altshuler et al., 1984), was that present societies are heavily reliant on the motor vehicle and hence the motor car was ‘here to stay’. The research was organised centrally from MIT yet also drew upon a range of outside faculty, such as

Marty Anderson at Babson College, as well as a number of international research teams in each country. Researchers such as Ulrich Jürgens, Koichi Shimokawa and Takahiro Fujimoto were already part of this phase. Equally, Dan Jones, who travelled to MIT for the first time in 1979 to meet with Dan Roos and Jim Womack, became UK team leader and later European director of the second phase of the programme. Jim Womack, who had completed his doctoral dissertation in political science with Alan Altshuler at MIT in 1983 (cf. Womack, 1983), became research director of the program in 1983, taking over from Marty Anderson. This network of international researchers was an important feature of the success of the programme, and many researchers that later contributed to the ‘Machine’ were already part of this early phase.

The programme published its first book at a time when growing Japanese imports became a serious concern to the Western producers. Henry Ford II, for example, called the Japanese imports ‘an economic Pearl Harbor’ (cited in Automotive News, ‘100 Events that made the Industry’, 1996, p. 144). From the start, the IMVP program hosted so called ‘policy fora’, where senior industry, government and union representatives came together in a confidential setting to discuss the latest research findings. These annual fora also permitted participants to actively guide the research agenda, a feature that IMVP has maintained to this day. The main topics of interest in the late 1970s were trade issues, in particular for the Western vehicle manufacturers who saw the import market shares steadily growing (see Fig. 1), so this became a major research focus.

By 1980, imports accounted for a total of 26.7% of U.S. passenger car sales, the large majority of which were from Japan (22.2%). With mounting political pressure, a voluntary trade agreement (VTA) was agreed between the U.S.A. and Japan in 1981 to restrict

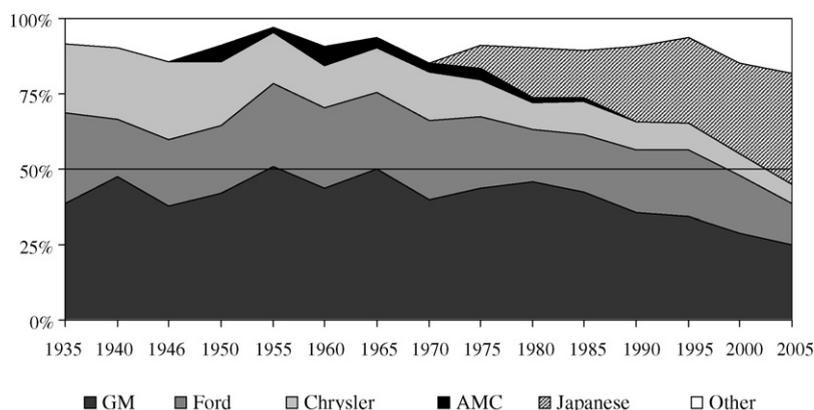


Fig. 1. U.S. Passenger Car Market Share by Company, 1935–2005. Excludes Light Trucks. Source: Wards’ Yearbooks, 1950–2005.

the number of imported vehicles into the U.S.A. With hindsight, one could argue that these agreements were in fact counterproductive: first, the overall number of vehicle imports was restricted, so the Japanese manufacturers imported upscale products, which were much more profitable, a practice which was instrumental in establishing the luxury brands of Lexus, Acura and Infiniti. Second, as of 1982 the Japanese established assembly plants in the U.S. in order to circumnavigate import restrictions (see [Appendix A](#) for a chronology of all North American transplant operations). The domestic Western manufacturers initially welcomed these transplant operations by the foreign manufacturers (a point to be returned to later).

However, the Big Three continued to rapidly lose market share, which, as Dan Roos describes, was ‘a burning issue at these policy forums at the time’, but since Japanese companies were present, discussing trade issues soon proved to be too contentious. As a result, the discussion moved away from trade and into more operational issues such as what drove the Japanese competitive advantage. At the time a range of explanations were given. The most common explanations (and with hindsight, misperceptions) were:

1. *Cost advantage*: Japan was seen to have lower wage rates, a favourable Yen/Dollar exchange rate and lower cost of capital, elements that combine to an ‘unfair playing field’.
2. *Luck*: Japan had fuel-efficient cars when the energy crisis came, or it was simply a fortunate effect of the ‘business life cycle issue’.
3. *‘Japan, Inc.’*: MITI, Japan’s Ministry of International Trade and Industry, was suspected of orchestrating a large-scale industrial policy.
4. *Culture*: Cultural differences in Japan allowed for more efficient production, which cannot be replicated in other countries.
5. *Technology*: The use of advanced automation in Japanese factories (‘It was all done with advanced robotics’). Some even suggested that the Japanese were acquiring Western technology, which they then exploited.
6. *Government policy*: Trade barriers against the U.S., more lenient labour laws in Japan, and a national health care program lowered the overall labour cost.

While there was considerable dissent about what gave the Japanese their superiority, the general fact that the Japanese were increasingly competitive was hardly in doubt. Several high-profile publications by academics, consultants and reports to government com-

mittees in the U.S. openly discussed the performance gap between the U.S. and Japan (Hayes, 1981; Abernathy and Clark, 1982). The first Harbour Report for example identified a US\$ 1500 cost advantage in the Japanese manufacture of subcompact cars (Harbour and Associates Inc., 1981). Abernathy et al.’s report on the U.S.–Japan performance gap already pointed very clearly towards manufacturing as the source of Japan’s competitiveness (Abernathy et al., 1981, p. 73–74):

‘... most explanations of this Japanese advantage in production costs and product quality emphasize the impact of automation, the strong support of the central government, and the pervasive influence of national culture. No doubt these factors have played an important role, but the primary sources of this advantage are found instead in the Japanese (...) execution of a well-designed strategy based on the shrewd use of manufacturing excellence. (...) The Japanese cost and quality advantage (...) originates in painstaking strategic management of people, materials and equipment – that is, in superior manufacturing performance.’

Abernathy and Kim’s research at the time was based on their experiences from a study tour to Japan in 1979 (which incidentally was also when they first met Takahiro Fujimoto, then at the Mitsubishi Research Institute). In Europe, the situation was little different. The opinion at the time was that little new was to be learnt about Japan’s competitiveness. In 1977, a representative of Ford of Great Britain stated before a government Select Committee that:

‘... all the processes and products used by the Japanese motor industry are known to us and their success depends on achieving economies of scale based on their large home market, on a different attitude adopted by labour in their industry and also their apparent success in containing inflation more effectively than we have been able to do in this country.’ (HMSO (1978), cited in Hill (1985)).

The ‘Future of the Automobile’ book did not specifically investigate the ‘Japanese phenomenon’, but alluded to it in chapter 7. In many ways, the book reflected the research agenda set in the policy fora, and hence focussed on long-term trends, exchange rates, trade and government policy. However, many features that were to be explored in more detail in the ‘Machine’ were already mentioned, such as the corporate organisation, the structure of supplier networks, and an initial crude comparison of labour cost difference per vehicle produced. The book was presented at the final

policy forum in 1985 and created a lot of attention, and the sponsors encouraged the research team ‘to look further into the issue of why Japan was getting ahead’*, as Dan Jones recalls. A key individual was Jay Chai, who was on the advisory panel of IMVP and was the CEO of C. Itoh at the time, where he had helped broker the agreement between Toyota and GM that led to the NUMMI (New United Motor Manufacturing) joint venture. He invited Dan Roos for dinner, and inquired about a follow-on programme. Dan Roos stated that to put such a programme together would require ‘a million dollars from each the U.S., Europe and Japan.’* Roos recalls his surprise when Chai said: ‘Ok I will get you the million from Japan, and if I cannot get it, I will give it to you myself’. He went straight to Shoichiro Toyoda, and persuaded the Japan Auto Manufacturers Association (JAMA) to join. This marked the start of Phase II of the programme in 1985, at which point it formally adopted the name ‘International Motor Vehicle Program’. Despite considerable difficulties in raising the additional funds in Europe, the programme went ahead and – contrary to Phase I – now centrally funded all international research teams from MIT.

4. The development of the assembly plant benchmarking methodology

In the second phase, the research remit was to not only describe the gap between the Western World and Japan, but also ‘to measure the size of the gap’*, as Dan Jones points out. In fact, various researchers had attempted to provide such international comparisons, and the use of labour input per vehicle produced as comparator had been proposed as early as 1959 (Maxcy and Silberston, 1959). However, this measure is fraught with several conceptual problems, as the labour input varies greatly by vehicle size and option content, as well as by the degree of vertical integration, i.e. to what extent the manufacturer produces components in house, or buys them in from suppliers (Silberston, 1964). Previous studies by Pratten and Silberston (1967), Jones and Prais (1978) and Abernathy et al. (1983) had explored various means of normalising the labour input, and several features proposed in these early studies were further developed in the IMVP methodology, such as for example the standardised car synthesised by Abernathy et al. used to compare labour, energy and material input per vehicle by country. However, a rigid methodology capable of considering vehicle size, option and labour content simultaneously was still missing, and so the IMVP researchers were met with strong scepticism with regards to the feasibility of conducting a global comparative study that would be able

to normalize the complex differences inherent in the motor industry. So, while there was a good understanding of the differences in manufacturing practices across regions, the way of executing a valid comparison was far less defined: as Dan Jones remarked, ‘we had a method, but we did not have a methodology’*.

The initial design of the benchmarking methodology was developed by Womack and Jones during 1985/86, and was tested at Renault’s Flins plant in 1986. In May that year, John Krafcik went to see Jim Womack to discuss potential research opportunities if he were to enrol at MIT. Krafcik was the first American engineer to be hired by NUMMI, so Womack recalls offering him to take part ‘in the first truly global benchmarking study of any industry’*. Upon his return, Krafcik resigned from NUMMI and joined MIT as an MBA student, and by summer 1986 Womack and Krafcik formally started the assembly plant study by visiting GM’s Framingham assembly plant in Massachusetts. In addition to the data from Flins and Framingham, Krafcik had the ‘before and after’ data for the GM Fremont plant that became NUMMI in 1984, as well as the data for Toyota’s Takaoka plant in Japan where he had been trained for his assignment at NUMMI. And it was this set of the four assembly plants – Flins, Framingham, NUMMI and Takaoka – that made up the first international assembly plant benchmark. Womack compiled the data of these four plants into a paper, which was presented by Krafcik at the 1986 policy forum, entitled ‘Learning from NUMMI’ (Krafcik, 1986). The paper showed that NUMMI, within its first year of operation, had achieved a productivity level more than 50% higher than that of the technologically similar Framingham plant, and achieved the best quality within GM’s entire U.S. operation. These results were particularly powerful, as NUMMI was a former GM plant that had been closed in 1982 after severe industrial action, but largely re-employed the same workforce and did not use any significantly different or new technology.

The 1986 paper had a very strong impact on the IMVP sponsor companies, and the research team thereafter were given strong encouragement from Louis Schweitzer at Renault and Jack Smith at GM (who had signed the NUMMI deal on GM’s behalf) to develop the study further. At the time the funding had been secured, yet both Roos and Jones recall the considerable time and efforts it still took in getting the industrial sponsors (in particular the Japanese companies) to grant access to their assembly plants.

Also, the benchmarking methodology continuously evolved by gathering feedback from sponsors and researchers. Krafcik used his shop-floor experience at

NUMMI ‘to come up with lots of clever proxies to measure the different aspects of manufacturing performance’,* as fellow researcher John Paul MacDuffie points out. For example, he suggested measuring rework areas in square feet to gauge the average amount of rework in a plant, and to use the weld content (i.e. the number of spot welds per vehicle) as a proxy for the vehicle size, thus addressing one of the most obvious sources of bias in the comparison – the size of the vehicle produced. This was in fact a key defence of the Western manufacturers at the time, explaining that the Japanese were more productive ‘because they are making smaller boxes’. This issue was addressed by assessing vehicle size as a total of all spot welds, the sealer content in relation to average world sealer content, and vehicle size in relation to average world vehicle size. In the assembly area, vehicle adjustments were based on option content and vehicle size. All vehicle adjustments were weighted by production volume of different products produced in the plant, and adjusted for vertical integration based on a key set of activities that were done in-house by most plants. Finally, differences in working time, breaks, and absenteeism were considered (for more detail see: [MacDuffie and Pil, 1995](#); [Holweg and Pil, 2004](#)).

Another MIT student, John Paul MacDuffie, also became involved in the programme at the time. MacDuffie was a student of Tom Kochan, who had enrolled at MIT’s Sloan School in 1985 to pursue his doctorate. In 1986, he was working as research assistant to Haruo Shimada from Keio University (a visiting professor at the Sloan School), who was interested in the Japanese transplants in the U.S., trying to understand how well they were able to transfer the Japanese human resource and production systems. Shimada was one of the first researchers allowed to visit and conduct interviews at the new transplants of Honda, Nissan, Mazda and NUMMI. Shimada used a benchmarking index according to which he classified companies on the spectrum from ‘fragile’ to ‘robust’ or ‘buffered’. This terminology that was initially used by IMVP researchers, but ‘fragile’ later amended to ‘lean’ which was seen to have a more positive connotation. The term ‘lean production’ was first used by Krafcik in 1988 ([Krafcik, 1988b](#)), and subsequently, Womack et al. of course used the term ‘lean production’ to contrast Toyota with the Western ‘mass production’ system in the ‘Machine’ book.

MacDuffie presented the joint work with Shimada at the same policy forum in 1986 where Krafcik presented his first findings ([Shimada and MacDuffie, 1987](#)). MacDuffie wanted to expand his research on work practices, but was not granted access to Mazda’s plant in

Flat Rocks, Michigan, so he went to see Womack to discuss measuring work systems more systematically. In 1987, MacDuffie formally joined IMVP, where he then developed the work systems methodology around the technical benchmarks by adding measures on teams, training, improvement and responsibilities. The benchmarking methodology of the first assembly plant study consisted of these two main elements: the technical or industrial engineering dimension of the production system, and a study of the work system comprising of organisational structure and practices, as well as human resource policies.

After the visit to Framingham, Womack handed the responsibility for the assembly plant study to Krafcik, who was later joined by MacDuffie. With support of the respective regional research teams, they completed visits to 70 assembly plants worldwide between 1986 and 1989. This usually involved three different visits to each plant: first to introduce the research and submit the questionnaire, a second meeting to report back and to resolve any outstanding issues, and a final visit to report the results back to senior managers giving a comparative view of the company’s performance in relation to the average. The first yet still incomplete results from the assembly plant study were presented at the meeting at Villadesta, Italy, in 1988, and were met with an outright rejection. Most sponsors literally told the research team to ‘go back and check the data’, as the numbers were simply seen to be wrong. The team went back, verified the data, and presented the complete benchmarking results and methodology at the policy forum in Acapulco, Mexico, in 1989.

Some companies did take early notice of the results. Carl Hahn, the CEO of Volkswagen at the time, had read the Villadesta report and as Dan Roos recalls ‘asked me and Dan Jones to see him. So we went, and he said he had read our report. He said that this research was very important, as this was the evidence he needed to make the change at Volkswagen.’* Renault also took the benchmarking results very seriously, and to this date continues to use the IMVP methodology to benchmark their assembly plant efficiency.

The assembly plant data provided the basis for chapter 4 in the ‘Machine’ book, as well underpinnings for respective Ph.D. and M.S. dissertations ([Krafcik, 1988a](#); [MacDuffie, 1991](#)) and several papers ([Krafcik, 1988b](#); [MacDuffie and Krafcik, 1992](#)). However, a key feature of the ‘Machine’ book was that it did not only discuss manufacturing operations, but also product development, supply chain and distribution issues. Here, a range of further researchers contributed. Michael Cusumano, for example, who had spent 2

years at Tokyo University and returned to Harvard Business School as a postdoctoral fellow in 1984. Based on his research in Japan, he completed a book on the history of the Japanese auto industry (Cusumano, 1985). At Harvard Business School, he gave a seminar in manufacturing management, which inter alia included a visit to GM's Framingham plant. Susan Helper, working on her doctorate in economics at Harvard at the time, was interested in vertical integration and took part in this course. For Helper this excursion was the first visit to an assembly plant, and a memorable one, as she observed 'people having little paper clip fights on the line, as workers could work ahead of time, and then mess around for a minute or two'. After completing her Ph.D. on supplier relations (cf. Helper, 1987), Helper joined Boston University as well as the IMVP research team, and contributed to the supply chain chapter of the 'Machine', alongside the works of Lamming (1992) and Nishiguchi (1990).

In 1986, Michael Cusumano joined the faculty at the Sloan School at MIT, where his research focus shifted to include product development in a range of industries, but he still lectured on his research in the automotive industry. His class at the time included John Krafcik, Kentaro Nobeoka, Antony Sheriff, and Takahiro Fujimoto (who was enrolled as a student at Harvard), all of which later joined the IMVP research team. Nobeoka developed his research into multi-project development (cf. Nobeoka, 1988, 1993), which later led to the book 'Thinking beyond Lean' (Cusumano and Nobeoka, 1998). In parallel, Fujimoto was developing his product development benchmarking study as his doctoral project (cf. Fujimoto, 1989), which was later published jointly with his advisor Kim Clark (Clark and Fujimoto, 1991). Further research on product development and technology transfer was contributed to the 'Machine' by Graves (1991) and Sheriff (1988).

Given that the results from the assembly plant study were strongly resonating with the industrial sponsors and a wealth of knowledge had been assembled on the automotive industry, it was decided to write a book to present the combined findings of the programme. Since neither Womack, Jones nor Roos had ever written for an industry audience before, Donna Sammons Carpenter was hired as the editor. Her remit was 'to write a story around the assembly plant data', but soon found this impossible and instead helped Womack and Jones to write a story, rather than an academic text. 'We had a lot of luck', comments Jones, 'learning from her how to write for an industry audience'. The book was published in 1990, just 1 year after the key findings had been presented at the sponsors meeting in Acapulco.

The global assembly plant data was undoubtedly the empirical backbone of IMVP, yet as Dan Roos argues, the 'Machine' crucially showed that lean was 'not just manufacturing, but in fact a holistic logic and management system that starkly contrasted with the traditional *masse* production approach'. The 'Machine' provided a much more comprehensive yet technically far less detailed picture of the Toyota Production System than previous books, and it included issues such as supplier management and product development. A large array of U.S. and international researchers further contributed to the 'Machine', such as Michael Cusumano, Susan Helper, Kentaro Nobeoka, Antony Sherriff, Toshihiro Nishiguchi, Richard Lamming, and Andrew Graves (for a complete list of contributors see acknowledgments section in the 'Machine' book).

As one would suspect, the assembly plant study has been criticised on various accounts, for example for its measurement process and a lack of secondary data (e.g. Williams et al., 1992). Although Williams et al. themselves fall short of a comprehensive explanation of the differences in performance, they particularly criticise IMVP's choice of the unit of analysis employed. In response, Dan Roos argues that the limitations of focusing on the factory were known from the start, but that the assembly plant was seen 'as a good proxy for what was going on in the industry, and measuring the differences'.

5. The role of transplants in the knowledge transfer

A parallel development to the research at the IMVP was the establishment of the Japanese transplant operations in North America from 1982 onwards. These transplants have been frequently mentioned in the research into JIT manufacturing and lean production (cf. Womack et al., 1990; MacDuffie and Pil, 1994; Pil and MacDuffie, 1999). However, I argue that their role in the knowledge transfer has been understated, as in fact they not only supported the adoption of lean practices in the Western manufacturing world, but in fact have been instrumental in this process for three reasons: first, they provided a 'laboratory' where the JIT system could be observed that was much more accessible than the Japanese mother plants. Schonberger, Hall and Krafcik had all learnt about TPS through their involvement with transplant operations.

Second, the establishment of transplant operations provided active support in developing the local supply base. Supplier support operations, such as Toyota's Supplier Support Center (TSSC), very effectively taught their U.S. suppliers about lean production and JIT, much

in the same way as Toyota, Nissan and Honda did in the U.K. at their respective transplant operations there. Key individuals, such as ‘Mr. Oba’ [Hajime Oba] of TSSC, are now widely known in the industry for these efforts.

Third, the successful transfer of Japanese manufacturing techniques and work systems dramatically answered the central question as to whether JIT was transferable or culturally bound to Japan (Schonberger, 1982c; Turnbull, 1986; Liker, 1998; Shook, 1998). This was essential, as much of the research that investigated and evaluated the performance of the lean producers had focused on Japan, and considerable emphasis was put on the fact that these were ‘Japanese manufacturing techniques’ (see for example: Schonberger, 1982a). Even by the mid-1980s when considerable knowledge about the Toyota Production System was available, the superior performance of the Japanese was still attributed to idiosyncratic factors, as discussed earlier in this paper. Coupled with misperceptions of the root causes for superior performance, this created a strong sense that the system could not be replicated in the Western world. When the Japanese car manufacturers set up their transplant operations in the U.S., initially to circumvent import restrictions, the domestic U.S. manufacturers were unworried. In fact, many welcomed the move as they perceived it as ‘levelling the playing field’* according to MacDuffie, since the Japanese would have to deal with the same unionised workers, environmental regulations, healthcare cost, and cost of capital. This confidence was further driven by the failure of the Volkswagen transplant in Westmoreland, Western Pennsylvania. The facility, originally owned by Chrysler, produced the Rabbit/Jetta models from 1978 until 1988, when it was shut due to significant problems with productivity and quality, as well as declining sales. When the Japanese transplants were established, many expected that the Japanese would face similar issues, in particular at Fremont, California, where NUMMI reopened a factory that under GM ownership had seen some of the worst industrial relations disputes at the time before it was closed in 1982.

NUMMI of course turned out to be a major success story and has been the topic of a range of labour relations studies (e.g. MacDuffie and Pil, 1994; e.g. Pil and MacDuffie, 1996, 1999). Under Toyota’s leadership, NUMMI’s productivity reduced labour input to 19 h per vehicle, down from 36 h previously. Defects dropped from 1.5 to 0.5 per 100 vehicles, and absenteeism decreases from 15% to 1.5%. In addition to using just-in-time production principles, Toyota reached agreements with the UAW (the main union of auto workers in the U.S.) to implement a teamwork-based working environ-

ment, fewer job classifications, and quality circles. Overall, the success of the transplants resulted in a change of perception. As MacDuffie points out, ‘NUMMI took away so many excuses of the Americans. Many previous books about JIT were framed as ‘this is a Japanese thing’, whereas one of main contributions of the ‘Machine’ was to show that the lean production concept is not ‘culturally bound’*. He sees this as the most important contribution made by IMVP. As Womack et al. (1990, p. 9) argue:

‘We believe that the fundamental ideas of lean production are universal – applicable anywhere by anyone – and that many non-Japanese companies have already learnt this.’

Nevertheless, even at companies such as GM that had first-hand experience through NUMMI, there was a considerable delay in accepting the message. Despite NUMMI’s outstanding success, transfer to other GM plants took many years. Roos comments that GM’s management at the time lacked commitment to implementing lean, and ‘seemed more embarrassed by NUMMI than enthused by its success’*. A key priority at GM at the time was the vision of creating highly automated assembly plants so implementing lean was not a top priority. And, although GM regularly sent its managers to NUMMI to see and learn, these visits were only conducted for brief periods, and the visiting team were not of a size to have the influence to disseminate their knowledge across the organisation.

6. From just-in-time manufacturing to lean production

The previous sections have outlined the key stage of development of the Toyota Production System, illustrated the establishment of the IMVP and its research approach, and commented on the role of the transplant operations in the knowledge transfer. In this section, the evolution of the academic debate will be outlined, investigating why the ‘Machine’ book reached such prominence.

As has been shown in Section 2, the Toyota Production System has continuously evolved since 1948 from within Ohno’s engine shop, and was gradually rolled out to the wider Toyota organisation, and extended to its suppliers as of 1965. During this time, it was not treated as a ‘secret weapon’, but in fact remained rather unnoticed for two reasons. First, it evolved gradually into the ‘Toyota Way’ and was not formally documented in a concise guideline. Second, as Ohno pointed out, until the oil crises there was little

outside interest in what Toyota was doing (Ohno, 1988). In fact, the first papers on TPS were co-authored by Ohno and other prominent members of Toyota's Production Control Department (Sugimori et al., 1977b,a; Ohno and Kumagai, 1980).

Unfortunately it is not possible to pinpoint exactly when TPS was formally documented. Takahiro Fujimoto points to Ohno's own book, 'Toyota Seisan Hoshiki' (Toyota Production System), which was published in 1978 and apparently was delayed due to internal politics. Also, it is likely that the first formal documents on TPS were the supplier manuals published by Toyota's Purchasing Administration Department (established in 1965), in order to teach suppliers about the requirements for operating a JIT-delivery system. It has not been possible to confirm the latter assertion with the Toyota Museum, and some experts doubt that there is a link between the establishment of the Purchasing Department and the documentation of TPS. Kazuo Wada for example argues that – according to Toyota's official history – TPS was not documented until the early 1970s (see the 'Shiryō-hen' section of the Japanese version of Toyota's 50th anniversary history).

While it cannot be resolved whether the supplier manuals of 1965 indeed mark the first formal documents of TPS visible externally, what is known is that the 1997 paper by Sugimori et al. (1977a,b) entitled 'Toyota Production System and Kanban System Materialization of Just-in-Time and Respect-for-Human System' was the first source available in English. This article is remarkable for three reasons: first, it stresses the importance of aligning work systems around the production system, whereas many of the early writers on Just-in-Time largely focused on the tools, such as Kanban or SMED. Second, the article was not published by academics, but by four managers of Toyota's Production Control department – including Fujio Cho, who in 1999 became president of the Toyota Motor Corporation. Finally, the article already contained an initial benchmark of four assembly plants, comparing Japanese productivity to U.S. and European cases in terms of vehicles produced per employee. Thus, it seems that Toyota was well aware of its productivity advantage at the time. Monden further points to a paper by Anderson Ashburn in the *American Machinist* in July 1977, as another early publication (Ashburn, 1977).

Following these initial papers, it took several years before wider academic and practitioner circles would pick up on the topic. The next thrust in the debate, according to Schonberger (1998), was given by a series of articles by Yasuhiro Monden in the *Industrial Engineering* journal (Monden, 1981a,c,b), as well as a

conference paper by Taiichi Ohno himself (Ohno and Kumagai, 1980). In 1979, these publications led to the establishment of a study group called the 'Repetitive Manufacturing Group (RMG)' under a grant from, and sponsorship of, the American Production and Inventory Control Society (APICS). The group held a meeting at Kawasaki's motorcycle plant in Lincoln, Nebraska, in June 1981 and exposed participants to Kawasaki's well-developed JIT system, a clone of Toyota's system. The study group included Richard Schonberger and Robert Hall who, based on their experiences, published seminal books on JIT (Schonberger, 1982a; Hall, 1983a). Less prominent publications also emanated from this study group include Hay (1988) and Wantuck (1989). In parallel, Yasuhiro Monden of Tsukuba University published his book on TPS (Monden, 1983).

The books by Schonberger, Hall and Monden played a major part in disseminating the JIT message in the Western world, and were accompanied by several key articles in academic journals (Schonberger, 1982c,b; Hall, 1983b; Schonberger and Gilbert, 1983; Schonberger, 1983a,b) and in the practitioner press (Monden, 1981b,a,c; Nkane and Hall, 1983). Common to these early contributions is a focus on shop-floor techniques and inventory reduction, with few sources exploring the wider organisational setting in the same depth as Michael Cusumano did in 1985 (Cusumano, 1985). In retrospect, one could also argue that 'zero inventories' or 'stockless production' were misnomers given that Kanban scheduling does indeed require a certain amount of inventory to establish the 'pull' scheduling, albeit very little in comparison to the amounts of work-in-progress inventory that were commonly found in mass production facilities. Following this initial range of publications, a wide range of articles followed in the years to come (for comprehensive reviews see: Sohal et al., 1989; Waters-Fuller, 1995), including the books authored by Ohno (1988) and Shingo (1981, 1983, 1988).

Outside the U.S., the JIT message was equally heard. In the U.K., for example, Schonberger and Monden were widely read and some academics learnt about JIT from Japanese companies with whom they were collaborating. Early adopters included companies like Lucas where John Parnaby was instrumental in adopting just-in-time practices (Parnaby, 1979, 1986). In the U.K. a particular debate on the 'Japanisation' of the British industry emerged—a term initially proposed by Turnbull (1986), and later developed by Oliver and Wilkinson (1992), and considerable research into the adoption of JIT manufacturing practices was published (Voss, 1986; Bicheno, 1990).

Thus there is clear evidence that by the time the ‘Machine that Changed the World’ was published in 1990, the knowledge of JIT/TPS was indeed wide spread, and the first non-Japanese success stories were publicly known – raising the simple question of what made the ‘Machine’ so distinctly different in telling the story of lean production? Here, there is surprisingly little divergence in the views of those involved in the IMVP research (and writing the book, subsequently) from the view of the early JIT pioneers. Their respective views will be portrayed in the following section.

6.1. *The authors’ view*

The success of the ‘Machine’ book actually came as a surprise to its authors. As Dan Roos points out, the sales ‘did the opposite of what books normally do: sales started out flat, and slowly climbed over time’*. Initial sales of the book were slow, and despite an early (but rather mixed) review in the *New York Times*, and the efforts of a public relations firm hired to help promote the book, sales remain slow for the best part of the first year. The *Financial Times* awarded the ‘Machine’ the ‘Business Book of the Year’ award in 1990, but its fortunes only changed when *Automotive News* wrote a feature story in December 1991, which coincided with the building crisis in Detroit. Only at this point did sales increase, and by the end of 2005 more than 600,000 copies in 11 languages had been sold.

The authors see the reasons for their success as a combination of several factors. First, a key driver was the readable, non-technical style of the book. The book was not geared at academics, but directed towards senior executives and government officials, which had major implications for its content and style. In the view of the authors, it was seen as necessary to ‘tell a good, readable story’ in order to reach this audience. Second, the book not only described the new system (as many other earlier books did), but was also able to contrast its performance with other systems in a global benchmark. The strong empirical base behind the book is seen as the clear differentiator to previous contributions. Further differentiation came from the fact that the book included data not only from Japan, but also comparative data from all other key regions. A common view at the time was that ‘previous contributions on JIT were largely tool-based, where people wrote up what they had learnt at Toyota and the U.S. transplants’*. Third, the book came out at the ‘right time, just when when people became aware of the crisis’*. Fourth, the book provides a more systemic treatment of the wider management system at Toyota. In Womack’s view, ‘the contribution of the Machine was to

present TPS as the operations element of Toyota’s total management system and to link this to the product development process, the supplier management process, the customer management process, and the policy focusing process for the whole enterprise. TPS in our usage was always about the factory. The real power of the concept of ‘lean production’ as we intended the term to be used and as we use it in [the] Machine was that all five elements were combined.’* Finally, and much to the surprise of the authors, the ‘Machine’ was being used in classrooms, which it was never originally intended to be.

At MIT itself, the initial reaction to the book was very mixed. While many colleagues were very complimentary about the book, the authors were also criticized for writing a non-academic book that was deemed as ‘too breezy’ and therefore ‘MIT-unworthy’. This was partly driven by the fact that the book was rather critical of GM, and several MIT faculty members had funding from the company at the time. Within GM, the response was mixed. Don Runkle for example, one of GM’s Vice Presidents for Engineering, came to give a guest lecture at MIT in 1990. He brought a suitcase with him, and during the lecture produced various books, including ‘Made in America’ (Dertouzos et al., 1989). He then took out a copy of the ‘Machine’, pointing out to the audience that he had been an undergraduate student at MIT and had attended executive programmes at the Sloan School, yet had not been taught about lean production. He went on to state that ‘in the auto industry, if we get things wrong, we have a recall. I think, Sloan should recall me.’ In Europe, there was much stronger criticism of the findings and opposition to the publication of the book. A particularly contentious issue was not surprisingly the discussion of the productivity of a luxury car plant in Europe, which was ‘expending more effort to fix the problems it had just created than the Japanese plant required to make a nearly perfect car in the first place.’ (Womack et al., 1990, p. 91). The directors had learnt from Phase I of the programme not to give a veto right to the sponsors, so in the end the issues were resolved and the publication went ahead.

6.2. *The external experts’ view*

Early JIT researchers outside of IMVP do unanimously acknowledge the strong impact the ‘Machine’ has had on disseminating the lean message. Hall and Schonberger both refer to the MIT brand name, a strong research base and good ‘marketing skills’ to explain the success of the book. In addition, the strong empirical base of 5 years worth of data, the popular and understandable writing style, and an easily remembered name for the

production system were seen as contributing factors. The name ‘lean’ is also regarded as helpful in disseminating the message, ‘as the previous name of just-in-time manufacturing came straight from Toyota, and carried a bigger onus of a Japanese origin for Westerners’*, as Hall argues. Schonberger further points out that ‘the name ‘lean’ was appropriate and played well to impatient Westerners, and especially consultants, who are always looking for something new to ‘hawk’*.

Hall further points out that those in the U.S. and Europe ‘that [had] made pilgrimages to Japan understood what was going on, but they were few in numbers. I was in that group. None had the resources to make the same comparisons as MIT, so the writing was descriptive.’* Furthermore, the timing is seen as critical—as Hall claims, ‘more people were ready to hear about it at that time’*. John Bicheno further argues that researching the car industry was instrumental in establishing the book as the industry is powerful, and neither Schonberger nor Hall explicitly focused on car production.

Finally, an interesting historical observation transpired from the above interviews, pointing towards the fact that many of the (now known as) ‘lean’ principles have in fact been applied throughout history. Womack and Jones refer to Samuel Colt’s concept of interchangeable parts and the early days of Henry Ford’s synchronized flow as antecedents of lean production (Womack et al., 1990; Womack and Jones, 1996b). Bicheno points towards the Royal Navy during Nelson’s time (1760–1780), which was able to match the 120-gun French and Spanish warships (later to be named ‘battleships’) with 74-gun ships (later to be named ‘cruisers’) simply because the Royal Navy not only practiced more than its opponents but also researched and disseminated these standardized operating procedures throughout the then very large fleet. Also, changeover reduction principles were instrumental for reloading the canons. Hall points towards the flow production line at Ford’s Willow Run facility, where 6792 B-24 bomber planes were built during the Second World War, out of a total of 19,256 planes delivered to the U.S. Air Force. According to Hall, further evidence of antecedents to lean production can even be found in the way Venetians built ships at the time of the Crusades, and much earlier, that the Romans had similar ideas for building warships in large numbers. The Roman army developed a system of continuous improvement and standardized encampments, which distinguished the Romans from their barbarian foes at the time. Hall argues that, ‘as for the long term history, evidence is that any time humans have engaged in mass production, concepts how to improve the flow and the process occur naturally.’*

7. Expansion of the research focus after 1990

The publication of the ‘Machine’ sparked a wealth of research into the adoption of lean practices that were initially confined to the automotive sectors, but soon expanded into other manufacturing and service operations. A detailed discussion of the evolution of this research is beyond the scope of this paper (see Hines et al., 2004 for a recent review). At MIT, the International Motor Vehicle Program continued its research into the motor industry through a third and fourth phase (1990–2001, and 2001–present), expanding its remit into the wider adoption of lean production in the supply chain, supplier relations (Helper, 1991; Helper and Sako, 1998), and the adoption and integration of new technologies such as e-commerce (Fine, 1998). In parallel, the assembly plant study was repeated after John Paul MacDuffie joined the faculty at Wharton in 1991. Jointly with Frits Pil, a doctoral student at Wharton, the second round of the assembly plant study was completed (Pil, 1996; Pil and MacDuffie, 1996). Pil completed the third round of the assembly plant study in 1999–2000 after joining the faculty at the University of Pittsburgh. The methodology has been evolving in each iteration to incorporate new variables, while maintaining the basic performance metrics in order to allow for longitudinal comparison. For a discussion of the initial productivity and quality metrics see Krafcik (1988a), Krafcik and MacDuffie (1989) and MacDuffie and Krafcik (1992). A discussion of the approach used in 1994 can be found in MacDuffie and Pil (1995) and Pil and MacDuffie (1996), and the results of the third round can be found in Holweg and Pil (2004). The regional distribution of plants in each study is as follows (see Table 1):

Several members of the research team left the programme after 1990, some leaving for appointments in industry as in the case of Krafcik and Sheriff, or setting up their own research centres. Womack, for

Table 1
The global assembly plant study: overview of participating plants

Regional Group	Round #1 (1989)	Round #2 (1994)	Round #3 (2000)
North America	16	25	23
Europe	24	21	14
Japan	9	12	8
New entrants	17	22	23
Other	4	8	3
Total	70	88	71

example, founded the Lean Enterprise Institute (LEI) to promote the implementation of lean thinking, and Jones left the Science Policy Research Unit (SPRU) at Brighton to join Cardiff University in 1989, where he set up the Lean Enterprise Research Centre with Peter Hines in 1994 to conduct research into the adoption of lean principles in a wide range of sectors, such as car distribution, grocery retailing, and health care. A key focus of Womack and Jones' subsequent work was on the implementation of lean practices (Womack and Jones, 1994, 1996a,b). As Dan Jones points out: 'We knew all about lean, but could not answer the question 'How do you get from here to there?''*

The IMVP model also had an impact on the organisation of other research programmes. In 1993 for example, a similar programme with an industry-consortium in the aerospace sector started at MIT, the 'Lean Aerospace Initiative'. Following the publication of the 'Machine' the U.S. Air Force had asked whether the lean principles could be applied to aerospace, and subsequently lean principles have been widely applied (and adapted) to both civil and military aerospace operations (cf. Murman et al., 2002). IMVP also served as a role model for the establishment of the Alfred P. Sloan Foundation's Industry Centers, each of which focus on research within one industry. IMVP's focus on systems and treatise of a complex industry also contributed to the establishment of the Engineering Systems Division at MIT, which uses an interdisciplinary approach to studying complex engineering systems, as common in the automotive and aerospace industries (Roos, 2003).

8. Concluding thoughts

In reviewing how the lean production concept was formulated and disseminated several striking facts about the mode and lead-time of adopting complex industrial practices have been revealed. One might argue that it took the Western manufacturing world nearly four decades to realise and address the superiority of Japanese manufacturing methods, yet this view is skewed. First, the lean concept itself was not a single-point invention, but the outcome of a dynamic learning process that adapted practices emanating from the automotive and textile sectors in response to environmental contingencies in Japan at the time (Cusumano, 1985; Fujimoto, 1999). As such, TPS was not formally documented until 1965–1970 (in Japanese) and 1977 (in English). Second, while the academic interest in Japanese manufacturing techniques reached a peak in 1977–1983 with a comprehensive set of publications on

JIT and TPS (see timeline in Appendix B), there was little interest by the Western manufacturers. The main reason behind the apparent 'ignorance' outside of academic circles in the early 1980s can be explained best by the fact that there was little need to be concerned about the competition from Japan until the oil crises saw a drastic increase in imports that started to threaten the domestic manufacturers. Even then frequent suggestions by leading researchers that Japan's competitiveness was derived from superior manufacturing performance were met with denial, and it was IMVP's comprehensive methodology and dataset that allowed a like-for-like comparison. In many ways the global assembly plant study results did not provide any fundamentally new insights, but they provided unequivocal empirical proof. Coupled with the visible success of the Japanese transplant operations in the U.S., it was now undeniable that lean practices not only yielded superior performance, but that these practices were not culturally bound to Japan and thus indeed transferable to other countries and organisations.

Further factors that differentiated the 'Machine' from previous books on JIT/TPS and made it such a powerful vehicle for disseminating the lean production message were the coincidence of its publication with a major crisis of the U.S. auto industry, its accessibility to practitioners by avoiding the technical language common to previous books, and a scope that went beyond manufacturing and provided a much larger remit than operational improvement in the factory. One could argue that the 'Machine' was a rather simplistic representation of the wealth of research undertaken by IMVP, a point reinforced if one compares the introduction of Krafcik's (1988b) paper and his discussion of industrial stereotypes with the main message of the 'Machine'. This argument misses the point though, as most crucially the 'Machine' book provided the industry with 'a story of fear and hope' at a time when it was obvious that the manufacturing industry was in distress. It graphically illustrated the extent to which the West was being overtaken by Japan and its superior manufacturing techniques, yet also provided hope that by adopting lean techniques this trend could be halted. It essentially made the manager the decisive element in the system determining whether his or her company would 'become a Toyota' or not, and hence set a clear vision for improvement in many organisations.

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Appendix A. List of transplant operations in North America

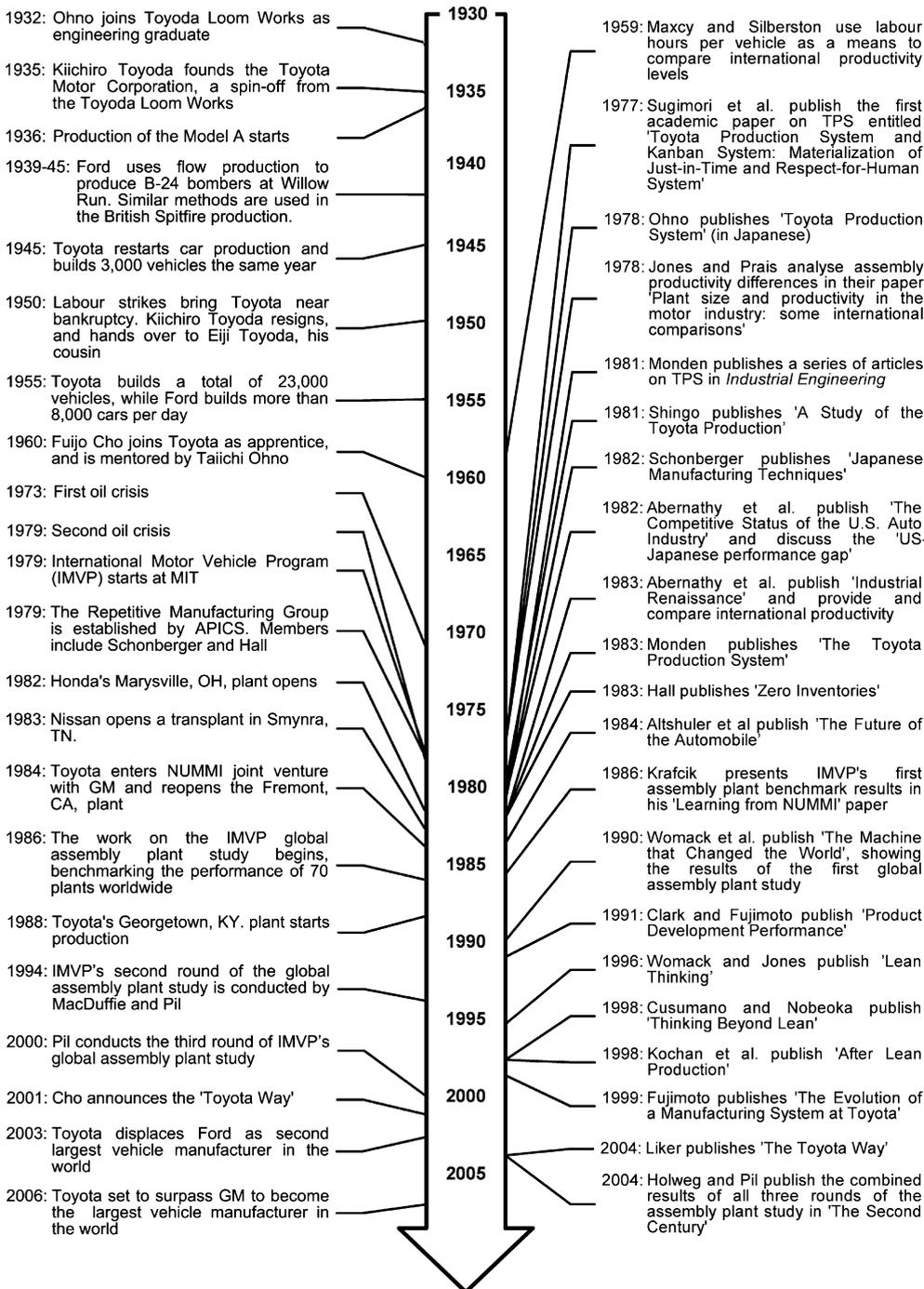
Manufacturer	Location	Start of operations	Products manufactured (past and present)
Volkswagen	Puebla, Mexico	1962	Beetle, New Beetle, Golf, Jetta, T2
Volkswagen	Westmoreland, PA	1978 (closed 1988)	Rabbit and Jetta (Golf)
Nissan	Aguascalientes and Cuernavaca, Mexico	1966	Nissan Tsuru, Sentra, Tsubame, Pickups, Lucino, Platina Renault Scenic, Clio
Honda	Marysville, OH	1982	Accord, Acura TL, CL
Nissan (NMMC)	Smyrna, TN	1983	Quest, Altima, Maxima, Sentra, Frontier, Xterra
NUMMI (Toyota/GM joint venture)	Freemont, CA	1984	Chevrolet Nova, Prizm, Pontiac Vibe Toyota: Corolla, Hilux, Tacoma, Voltz
Honda	Alliston, Ont., Canada	1986	Odyssey, Civic, Acura EL, Acura MDX, Pilot
Mazda (Auto-Alliance International, owned by Ford)	Flat Rocks, MI	1987	Mazda 626 MX-6 Mercury Cougar, Probe Ford Mustang
Mitsubishi (formerly Diamond Star Motors, a joint venture with Chrysler)	Bloomington-Normal, IL	1988	Mitsubishi Eclipse, Galant, Mirage Plymouth Laser, Chrysler Sebring, Dodge Avenger, Stratus, Eagle Talon, Eagle Summit
Toyota (TMMK)	Georgetown, KY	1988	Camry, Avalon, Solara, Sienna, Pronard
Toyota (TMMC)	Cambridge, Ontario, Canada	1988	Camry, Corolla, Matrix, RX330, Solara
Honda	East Liberty, OH	1989	Accord, Civic, Element
Subaru-Isuzu Automotive Inc. (joint venture)	Lafayette, IN	1989	Isuzu Rodeo, Axiom Subaru Legacy, Baja, Outback Honda Passport
CAMI (Suzuki/GM joint venture)	Ingersoll, Ont., Canada	1989	Chevrolet (Geo): Metro, Tracker, Equinox Pontiac Firefly Suzuki: Swift, Sidekick, Vitara
Avon Lake (Ford-Nissan joint venture)	Avon Lake, OH (prev. Ford plant)	1993	Lincoln/Mercury Villager Nissan Quest
BMW	Greenville (Spartanburg), SC	1994	Z3, Z4, X5
BMW	Toluca, Mexico	1995	3 series
Honda	El Salto, Mexico	1995	Accord
Mercedes-Benz	Vance (Tuscaloosa), AL	1997	M-class
Toyota (TMMI)	Princeton, IN	1999	Tundra, Sequoia, Sienna
Honda	Lincoln, AL	2001	Odyssey
Nissan	Canton, MS	2003	Quest, Titan, Pathfinder, Armada, QX56
Hyundai (HMMA)	Montgomery, AL	2005	Sonata

Appendix B. The research and dissemination of lean production—a time line

Note: For a timeline of the developments within Toyota see [Ohno \(1988\)](#); for a timeline of the concepts that contributed towards the development of lean production see [Bicheno \(2000\)](#).

Key Events

Major Publications



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