WHAT WAS THE ASSEMBLY LINE ?

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INTRODUCTION

Today, ”assembly line” immediately suggests Asian or Latin-American factories where poorly-paid workers make consumer goods for export to the West. For example, many US corporations shifted jobs to northern Mexico beginning in 1965 as part of the Border Industrialization Program. This process accelerated dramatically after January 1, 1994, when the North American Free Trade Agreement (NAFTA) went into effect. It abolished tariffs and made re-importation of assembly line goods easy. By 2000, 1.2 million US jobs had been relocated to Mexico. Most of the Mexicans hired were semi-skilled women, preferred both for their manual dexterity and their willingness to accept low wages.[1] Corporations built factories where environmental legislation was lax and unions were weak or non-existent. In such places, “the danger is that repression rather than innovation becomes a competitive advantage.”[2]

Yet if the assembly line of today is often part of a global production system for offshore, semi-skilled work, at its inception in 1913 the Americans saw the assembly line as the guarantor of high wages and domestic prosperity. This essay reviews the origins of the assembly line, what exactly it was as a technology, and how it was initially understood. In hindsight, it was less a beginning than a mid-point in long-term developments that are still underway.

Historians frequently refer to the assembly line as an historical stage, in a sequence from Taylorism to Fordism to “post-Fordism,” with additional stages sometimes included such as “flexible production,” “lean production” and most recently “post-lean production.”[3] As convenient as these historical stages once seemed, their proliferation suggests that the whole notion of a sequence was mistaken to begin with. Indeed, many historians of technology no longer write about a sequence of stages.[4] Moreover, the public response to the assembly line in the years 1913 to 1920 suggests that it was not seen as a radical break with previous factory systems, but rather as the culmination of decades of incremental changes in manufacturing. Nor did the assembly line emerge out of, or replace, Taylor’s scientific management.

1 Livingston 2004, 59-76.
2 Shaiken 2009, 56; Klein 1999.
3 Among the myriad writers to use “Fordism” to refer to the assembly line, see Burrows 1992, or Tolliday and Zeitlin 1987.
4 See, for example, Hounshell 1984 and Biggs 1996.

Rather, it was part of a series of process (as opposed to product) innovations that began in the eighteenth century and that is still underway.

ORIGINS

The assembly line emerged at the Ford Motor Company, whose new 1910 Highland Park Plant provided a setting conducive to manufacturing innovation. No single individual invented the assembly line. It was a collaboration between many people, who drew on knowledge acquired in many different industries. A leading scholar in the study of technology, Anthony F. C. Wallace, concluded after a lifetime of research:

> We shall view technology as a social product and shall not be over much interested in the priority claims of individual inventors, for the actual course of work that leads to the conception and use of new technology *always* involves a group that has worked for a considerable period of time on the basic idea before success is achieved.[5] (Emphasis in original)

This generalization applies with particular force to both the assembly line and its eventual reconception as lean manufacturing. In each case, a group worked together for years to rethink the fundamental processes of production.

Manufacturing processes that in hindsight look much like an assembly line can be found long before Henry Ford founded his company in 1903. The idea of moving work to the men, who remained in fixed locations along a line where each performed a single function, had been developed by slaughterhouses before the Civil War. Their "disassembly" lines began with live animals being driven into the building and ended with cuts of meat, hides, tallow, and other products.[6] In a sense, Ford reversed this process. Another central element in any form of mass production is interchangeable parts, which were so widely used in the United States that Charles Fitch examined them in detail in his "Report on the Manufacture of Interchangeable Mechanism," as part of the *Tenth Census of the United States* (1881). The canning industry's continuous flow production was another precursor to the assembly line, and historians have noted others, some of which Ford or his staff conceivably might have heard of, such as the Venetian arsenal's production of ships or Josiah Wedgewood's manufacture of pottery to a high and uniform standard. In the United States, before 1800 Oliver Evans devised gristmills with continuous flow production that produced flour almost without the touch of a human hand. By 1804 the British Navy mass produced biscuits. Dough was mixed in "an ingenious machine" and the subsequent work was divided into six tasks, the last being to place the biscuits in a

5 Wallace 2003, 3.
6 Arms 1959.

long oven, through which passed a conveyor. Out the other end came the biscuits, 70 per minute. By the 1830s most of this process had been mechanized.[7]

Some historians, rather than search for manufacturing processes that prefigured the assembly line, trace the development of a new mentality amongst workers, engineers, and managers. Lindy Biggs studied the American pursuit of "the rational factory" from Oliver Evans and Thomas Jefferson in the late eighteenth century to the culmination of this quest in the Ford manufacturing system. Biggs was concerned not only with particular technologies but also with the development of a mentality in search of – and an incentive system that rewarded – each rationalization. For example, in the textile industry, "mill mechanics quickly learned that production enhancing innovations earned rewards, and these bright, skilled men had little trouble introducing regular changes that increased speed or lowered skill requirements."[8] Industries rationalized in different ways. The paper industry did not seek to lower wages but to increase productivity. The arms industry sought greater precision in order to make interchangeable parts. In contrast to these fabrication industries, processing industries such as steel making, canning, or oil refining did not so much replace skilled workers as they accelerated the flow of materials. More generally, Biggs documents how in the last decades of the nineteenth century engineers invented what would now be called systems management, including cost accounting, inventory control, incentive wages, and standardization of work routines. Labor-saving machinery, accelerated materials handing, and systems management all came together in the Ford assembly line, which culminated a century of effort.

Seen in this way, the assembly line was not unique, but rather part of a long-term process of improving efficiency. Indeed, this seems to be how Americans first regarded the assembly line when they became aware of it. At first the term "assembly line" was only used in the technical press. A typical example from 1914 in *Engineering Magazine* runs, "finishing and assembling of front-axle components shows how labor-costs may be [...] reduced [...] by the use of sliding assembly lines, chain-driven for the final assembling, but having the partial assemblies moved by hand."[9] In contrast, the *New York Times* did not quickly adopt the phrase "assembly line". In January 1914 it published a full-page story on the Ford Motor Company, including six photographs. None was of an assembly line, and the new system of production was neither named nor was it the focus of the story. The first mention of the new manufacturing system by name in the *Times* did not come until as late as 1923, in an article about Studebaker.[10] Contrary to what one might expect, the

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7 Giedion 1948, 87-90.

8 Biggs 1996, 17.

9 Arnold 1914, 858.

10 Based on a search using the *New York Times* search engine, "assembly line" first appeared in "High Motor Value at Low Prices Attained in Quantity Production," January 7, 1923.

phrase "assembly line" was not widely used between 1914 and 1920. This in itself suggests that the public did not perceive a radical break with the past, but rather a continuation of improvements in efficiencies. For example, in the 1860s petroleum producers developed continuous process systems that tripled output while cutting costs in half. By the end of that decade the Bessemer process enabled steel production to speed up, and in the 1870s iron, copper, zinc, and glass companies also adopted continuous process technologies.[11] By 1908 sheets of glass could be rolled out in any size desired.[12] By 1913 Americans had come to expect enormous improvements in manufacturing efficiency, and the assembly line was but one more example of a trend.

Robert Friedel has found that "a culture of improvement" characterized western societies for at least a millennium. He argues that from the eleventh century onwards incremental improvements and the sharing of knowledge account for the West's mechanization and industrialization. In the case of the assembly line, he notes, it "was not, apparently, the result of some sort of overarching plan to reform manufacture. It instead grew out of the Ford engineers' effort to reduce perceived inefficiencies – their pursuit of step-by-step improvement of the production process."[13] The ability to perceive inefficiencies itself was the cultural outcome of centuries of hard-won practical knowledge from many industries. Those working at the Ford Motor Company when the assembly line was created had experience in arms manufacturing, bicycle production, meatpacking, steel making, and brewing. The assembly line synthesized practices from each of these, and became more than the sum of its parts. It thus exemplifies Wallace's observation that inventions emerge from a group, illustrates Friedel's argument that even the most important innovations are created incrementally, and offers the logical conclusion to Biggs's study of the how the rational factory evolved.

The most important study of the evolution of US manufacturing methods remains David Hounshell's *From the American System to Mass Production, 1800-1932*.[14] To explain the emergence of the assembly line, he traced, in case studies based on archival sources, the manufacture of sewing machines, several woodworking companies (including the Studebaker wagon works), the McCormick reaper factory, and several bicycle manufacturers. As the list of case studies suggests, Hounshell focused on fabrication industries that produced complex machines. In these industries developed the division of labor, specialized machine design, metal stamping (rather than casting), rationalization of workflow, and improved shop layouts that would converge in the assembly line. Most industries moved only haltingly toward fully rationalized production. Neither the Singer Sewing

11 Beniger 1986, 246.
12 Boorstin 1974, 343.
13 Friedel 2007, 471.
14 Hounshell 1984

Machine Company nor the McCormick reaper works, for example, adopted the New England armory practice of specialized single-function machines or the goal of fully interchangeable parts until they had been in operation for decades. What forced them to change? Not abstract logic but the pressure of increased sales. The woodworking and furniture industries incorporated many elements of production that eventually were used in the assembly line. However, because consumers wanted variety and because styles changed often, their "product lines could not be maintained long enough to justify the construction of special purpose machinery and other 'efficient' production techniques."[15] The Pope Bicycle Company continued to hand forge many parts until near the end of the century, and it did not solve the problem of efficient assembly before demand for its high wheel cycles declined. In short, each of these industries contributed to the eventual emergence of the assembly line, but none managed to integrate all the separate improvements into a new system of production. Part of the reason for this was the form of the factory itself.

CONTEXT

What was the physical context for the invention of the assembly line? With few exceptions, the factories of c. 1900 were steam-powered and had a completely different architecture than an assembly-line plant. A steam-powered facility was almost always built several stories high, with the power source centrally located on one of the lower floors. The power moved to the machines by gears, line shafts, and belts, and machines had to be arranged in straight rows to get power from the overhead drive shafts. Because power was transmitted as physical movement, a great deal of power was required just to run the transmission system itself. The larger a factory became, the greater the investment in shafts, belts, and gears and the more power had to be used to turn them. Practically speaking, in a really large plant it was necessary to build and maintain several power systems, with power radiating outwards from each.

Electric drive transformed the architectural possibilities. A factory that relied on electric motors could be built in any size and shape, and laid out according to the nature of the work. However, electric generation only became available in the 1880s, and reliable motors did not exist until the 1890s. As late as 1900, only 3.6% of factory power came from electric motors, rising to 18.7% a decade later.[16] Furthermore, many of the early electric motors were simply attached to the overhead drive shafts that already existed, or they were rigged up to drive a small cluster of machines. To build an assembly line required a further step. Every machine needed to have its own motor before they could be moved into more efficient positions, no longer dependent on external power sources such as drive shafts, gears, and belts.

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15 Ibid.,151.
16 Duboff 1979, 82.

Likewise, once transmitting power over a distance ceased to be a problem, factories did not need to be multi-storied structures with the power source in the middle. A sprawling single-story structure was often best suited to materials handling. Production was further accelerated by electric cranes, elevators, ventilation, and illumination, which together made possible a building of any size, height, or shape. With electric lighting there was no need to halt production because of darkness, and a factory could operate day and night if demand warranted it. Individually, each of these changes accelerated production. Collectively, they were preconditions for the assembly line.

While the components of the assembly line all preceded it, there seems no doubt that their integration first occurred in Henry Ford's factory between 1908 and 1913. Electrical drive spread quickly in fast-growing new industries such as automobile factories. They were a likely place for production innovation because the demand for cars continually outraced supply. Furthermore, automobiles were suited to developing something like an assembly line because they were made from a large number of parts. The Model T contained about 10,000, and the number increased somewhat between 1908 and 1916. In the early years workmen built stationary cars up from the floor, starting with the wheels and chassis and moving each part to the embryonic car. Each team of workmen had to be familiar with a large number of operations and procedures. This system wasted time as workers moved about a large floor looking for parts, and it created chronic inventory and supply problems. It was impossible to keep all the parts close to all the cars under construction. As orders for new cars poured in, the search for more efficient methods intensified. One possibility was to create teams of workers that each had a certain specialty and send them around from one car under construction to the next. But specialized crews were only slightly more efficient, as it was still difficult to keep all the parts that each crew needed nearby, and at times they had to wait for another crew to complete its operations. It was clearly more efficient to move the parts to the men, who stayed in place, and to subdivide the work. However, moving parts and materials continuously was difficult in a traditional factory building.

In order to produce a standardized car aimed at the largest possible market, Henry Ford built a new factory at Highland Park in Detroit. It opened on January 1, 1910. It was not designed with the assembly line in mind, but it was a new kind of facility, built on the assumption that electrical light and power should be available everywhere. The factory's floor plan was more open and flexible than older facilities. The buildings spread over a large area, providing managers with a space that encouraged innovation. Good lighting facilitated precision work, which was essential in order to achieve the exacting standardization needed to make interchangeable parts. Ventilation was just as important, as dust makes machines malfunction when working at close tolerances. At Highland Park electric fans swept out eleven million cubic feet of air every twenty-five minutes. Dust was extracted from the air by passing it through a heavy mist. The air was then dried and pumped into work areas. Pure air improved worker health, and it kept machinery cleaner and more accurate.

In this new facility, managers and engineers came together who collectively knew most of the manufacturing practices used in the United States. So many different people were involved that it is impossible to be sure who originated the idea. Ford's precise role in the invention of the assembly line is also unclear. He had worked as an electric power-plant engineer for Detroit Edison, as a mechanic in machine shops, and as a watch repairman, giving him experience with electricity, mechanics, and precision work. He certainly grasped the importance of both electric drive and interchangeable parts. At the least, Ford deserves credit for his support of the process of experimentation itself, which included many discussions with his staff. He also deserves credit for recognizing that automobiles could sell to a mass market if prices were greatly reduced. But Ford also hired talented managers who made major contributions to the assembly line. Some of them were machinists that had started out as workers. As Hounshell demonstrated, collectively they had an enormous expertise. To take just a few examples, the Yankee mechanic William Flanders knew the sewing machine business and championed interchangeable parts and single function machine tools. Max Wollering had worked for International Harvester and a gas engine company. Oscar C. Bornholdt had direct experience with canning and food processing. William Klann had worked as a machinist in flourmills and breweries. A whole crew of experts at punching and stamping steel moved to Detroit when Ford bought their company in 1911, including William Knudsen, who later directed several assembly line plants and eventually left for General Motors, where he became president. Another Ford manager, P. E. Martin, toured Chicago meat packing plants to garner new ideas for automobile assembly.[17] These men and many others together created the assembly line so rapidly that precisely who contributed which idea or implemented what process at what date may forever elude historians. They were too busy to make notes at the time, and many changes occurred simultaneously. However, if it is impossible to determine the precise contribution of each, it appears that Ford himself did not first conceive of the assembly line. Consider the testimony of Richard Kroll. He worked at the Piquette Plant, made the move to Highland Park, and was personally involved in the development of the assembly line. Kroll declared in an interview years later: "I don't know who thought up the idea of putting the whole car on a moving line." Yet he did recall "Mr. Ford didn't like it at first. He went on a trip somewhere, and while he was on that trip, they put the line in."[18]

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[17] Hounshell 1984, 220-228, 239-241.

[18] Kroll 1955, 15-16.

SIX DEFINING FEATURES

Rather than attempting to sort out the myriad personal contributions to the invention of the assembly line, it is far more useful to explain its six defining features. One principle of the assembly line is the subdivision of labor, described as early as 1776 in Adam Smith's *Wealth of Nations*, in a famous passage on the manufacture of pins. He noted that a person working alone could perhaps not make twenty pins in a day. Strict division of labor made an enormous difference in productivity.

One man draws out the wire, another straightens it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires two or three distinct operations; to put it on, is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into the paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations, which, in some manufactories, are all performed by distinct hands, though in others the same man will sometimes perform two or three of them.[19]

A team of ten or more people with only minimal skills together could produce and package 48,000 pins in a day. Smith noted that such enormous increases in productivity occurred in every industry where division of labor was introduced, and could be attributed firstly to "the increase of dexterity in every particular workman; secondly, to the saving of the time which is commonly lost in passing from one species of work to another; and lastly, to the invention of a great number of machines which facilitate and abridge labor, and enable one man to do the work of many."[20] Smith also noted that such new specialized machines often were created or proposed by workmen who focused all their attention on a single operation. Its repetition led them to imagine better tools and physical arrangements.

At the Ford Motor Company, managers subdivided work into many small operations of nearly equal duration. A study made in 1952 found that the typical job on an assembly line consisted of performing one or two small tasks that together took two minutes. For the assembly line to work smoothly, it was important that the precise time needed for each task be calculated, so that the correct number of workers could be allocated to each station on the line. There was variation. Some jobs took less than a minute, and a few might require as long as eight minutes, including some walking along the line, but the norm in 1952 was two.[21] (The evidence suggests that on the 1914 line the typical job took less time). To keep the line moving steadily, four times as many men were needed for eight-minute tasks as for those that took only two minutes. Another advantage of making the tasks brief was that every job could be learned quickly. Not only could virtually anyone work at Ford, but also workers

19 Smith 1776, Book 1, Chapter 1.
20 Ibid., Book 1, Chapter 1.
21 Walker and Guest 1952, 12.

could be moved around depending on need. Skills were no longer important, as most jobs could be learned immediately, with almost no training. Indeed, managers found that people who were blind or had disabilities could do certain jobs just as well as anyone else. The company made a comprehensive analysis and found that there were 7,882 different jobs in the factory. Of these, only “949 were classified as heavy work requiring strong, able-bodied” men. Another 3,338 jobs could be done by anyone in ordinary physical condition. But the “remaining 3,595 jobs were disclosed as requiring no physical exertion and could be performed by the slightest, weakest sort of men.”[22] In fact, 670 could be done by men with no legs, 2,637 by men with only one leg, 715 by one-armed men and 2 by men with no arms. Based on this analysis, Ford argued in his autobiography that the greater the subdivision of industry the more likely there would be work for everyone. He did not say, but surely knew, that workers who were blind or one-legged seldom quit. Healthy workers without disabilities were likely to flee the repetition of the assembly line. However, the most talented of them often escaped the monotony into skilled work, as the line itself had to be built, kept in repair, and constantly improved.

A second idea essential to the assembly line was interchangeable parts. Identical parts had to fit smoothly together without the need for any last-minute adjustments such as sanding or filing or polishing. The origin of this idea can be traced back at least to the early eighteenth century. As Ken Adler has noted, “In the 1720s, Christopher Polhem, a Swedish inventor, manufactured clocks composed of interchangeable parts.” In France a locksmith did something similar. By the end of the eighteenth century, one private French manufacturer was able to produce 10,000 gunlocks a year, through a process that divided labor into 128 separate steps.[23] In the United States, Eli Whitney promoted the idea of interchangeability, but did not achieve impressive results.[24] Whitney convinced Thomas Jefferson of the advantages of interchangeable parts for the production of weapons, and received a contract to realize the idea in practice. However, he proved unable to make metal parts to the exacting precision required. The idea was pursued in American armories, clock makers, and other manufacturers, and it was gradually realized during the nineteenth century. Interchangeable-part manufacture required such high standards of precision, however, that for generations it cost more than older methods of production, which in some industries remained competitive until well after the 1860s. Yet continual small improvements in machine-tool accuracy made parts more exactly alike and cheaper to produce. Ford managers achieved the necessary standards of precision partly by adopting the armory practice that each machine should perform only one function. A machine tool could be adjusted to make an almost infinite range of parts, but much time was needed to make

22 Ford 1922, 108.
23 Alder 1997, 297, 301-302.
24 Smith 1981, 45-61.

each adjustment. For assembly lines to be efficient, each machine was designed to perform only one thing, and to do that as quickly as possible. Furthermore, as the scale of production increased it became economically advantageous to invest larger sums in such machines, including some that no small manufacturer could afford. At Ford, the value of plant and equipment almost doubled between 1909 and 1917, when it reached $1606 per employee.[25]

Single function machines themselves were necessary but they were not sufficient to make parts that were precisely identical. To improve precision, electric drive was needed. Mechanically driven shafts inevitably had a tiny wobble that imparted a slightly different speed to machines further away from the power source. Likewise, a drive shaft moved slightly irregularly. It turned more slowly when more belts were engaged to drive machines, and as one specialist noted, “each shaft oscillates, each belt slips and creeps” and the “variation of speed caused by one class of machinery is reflected to the other machines all over the mill.”[26] These slight variations in the speeds of different machines along the line translated into slight variations in the products they manufactured. It was difficult to make absolutely standardized parts without electric drive in each machine, which provided a reliable standardization of speeds and work performance. Likewise, the use of electrical heating spoiled fewer materials than other kinds of heat and speeded up steps in the assembly process, such as drying paint on individual parts. Overall, electrification permitted a higher and more predictable standard of parts production.

A fourth idea that Ford managers developed also originated with arms production: that machines should not be grouped by type (e.g. all punch presses together) but arranged according to the sequence of work needed to create each product. Ford could rearrange production in this way because machines driven by electricity could be placed in any order on the shop floor. Furthermore, stronger construction techniques made it possible for Ford to place heavy machinery and even a foundry on the top floors of its 1914 Highland Park shops. Before then, the weight of machinery and the problem of vibrations had made it advisable to place this work on the lowest floor. The new arrangement meant that the upper floors fashioned raw materials into parts that then “flowed” to sub-assembly lines on lower floors, before arriving at the main assembly line on the ground floor. Each completed car could then be driven right out of the building into the parking lot.[27] These changes had immediate effects. The leap in productivity in 1911 alone was phenomenal, as the new plant made it possible almost to double the number of cars being produced per man.[28] Thus two years before the assembly line was put into place, the adoption of four of its five major features – subdivision of labor,

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25 Williams, et al. 1998, 225.
26 Woodhouse 1910, 30.
27 Biggs 1996, 123-125. On Ford architecture, see Ling 1990, 127-167.
28 Williams, et al. 1993, 74.

interchangeable parts, single-function machines, and the sequential ordering of machines – doubled productivity.

Much of the productivity improvement realized at Highland Park was achieved through more efficient in-house production of parts. In the first years of manufacturing the Model T the cost of buying parts from outside suppliers was high. Fully two-thirds of the cost of parts was due to the inefficient production of (as well as the profits made by) outside suppliers. At Highland Park Ford manufactured more of its own parts, and did so more cheaply than suppliers could, driving down the percentage of outside components in the Model T. One team of historians estimated that between 1909 and 1916 the cost of materials per vehicle (including raw materials and manufactured parts bought elsewhere) dropped by half from $590 to $262.[29] Moreover, the increased capability to produce parts in-house pressured remaining suppliers to lower prices or risk losing their contracts. By comparison, the cost of wages was a far less important factor in the final cost of manufacturing a Model T, and remained relatively low at $64 to $70 a vehicle, except for higher costs during the year Ford moved into Highland Park.[30]

Fifth, this system worked even better if parts and sub-assemblies were moved automatically from one stage of production to the next. The most conspicuous elements of the assembly line – its gravity slides and continuous moving belts – are often mistakenly understood to be the most important ones. Before 1900, flourmills, bakeries, brewers, and cigarette companies operated continuous-process machinery, particularly in conjunction with ovens. Ford himself had seen a striking application of materials processing and handling at Thomas Edison's iron mining facility in Ogdensburg, New Jersey. Since Ford idolized the famous inventor, this example is particularly important as a precursor to the moving belts of the assembly line. Edison extracted iron from low-grade magnetite. His operation blasted five-ton boulders out of a mountainside, smashed them into progressively smaller pieces, ground these into sand, and then pulled the iron particles out of that sand by pouring it past powerful magnets. To transport the progressively smaller stones Edison developed rubberized conveyor belts at the site in collaboration with Thomas Robbins, who set up his own company to manufacture vulcanized rubber belts in 1896. This mining site and mill was a suggestive precursor for the assembly line. Both integrated machines with moving rubber conveyors in a single overall plan that moved materials continuously.[31] Based on it and the practices of brewers, meatpackers, canneries, and flour mills, Ford and his managers adopted gravity slides and the moving belt, which brought the task to the worker at the best possible height so as to eliminate heavy lifting, bending, eyestrain, or other discomfort.

29 Ibid., 74.

30 Ibid., 76.

31 Nye 1983, 66-70.

Just as importantly, the space of production shrank, as Ford's managers sought to reduce in-process inventories and reduce the handling of materials to a minimum. For example, the distance traveled by the engine block was cut down spectacularly from 4000 feet to just 334 feet, and this reduced the number of partially completed engine blocks along the line by more than 85 percent.[32] At the same time more than twenty jobs for hand-truckers were completely eliminated. Thus the assembly line was not only a matter of bringing the work to the worker, but of shrinking distances, automating movements, and reducing inventories.

These five practices – subdivision of labor, interchangeable parts, single-function machines, the sequential ordering of machines, and the movement of work to the man via slides and belts – together define the assembly line as a physical technology. A sixth factor, factory electrification was a necessary precondition before these elements could be improved individually and welded together into a new form of production. Indeed, the value of electric lighting itself should not be overlooked. As late as the 1930s Ford managers found "that there is a direct relationship between the maintenance of adequate illumination and the production efficiency of the various departments" so much so that lighting was seen as "another production tool which is just as important as are modern types of machine tool equipment."[33] At the Highland Park Plant these practices all came together, making possible an immediate leap in productivity in 1911, with smaller increases in 1912 and 1913, followed by another leap in throughput in 1914, the first year that the assembly line was in full operation.

A corporation that adopted all of these practices to create an assembly line manufacturing system still needed to take on board another essential idea: make only one product and minimize changes in its design. Adam Smith's pin makers and the British Navy had early grasped this idea. Likewise, The Ford Motor Company understood that if it made a variety of cars each would require its own assembly line, and each would need its own continuous stream of parts. Likewise, changing the model of any car would require closing down an entire assembly line for time-consuming retooling. Therefore, Ford made only the Model T, though contrary to popular memory the color was not always or only black. Consumers could also choose between a hard metal top or a leather top that folded down behind the back seat, plus a few other options that varied from year to year.

The assembly line eliminated waste motion and bottlenecks in production, and accelerated productivity. This was most obvious in the final assembly. Using the older methods in 1909, assembling a single Model T required more than twelve hours of labor; by 1914 it took one hour and thirty-three minutes. To put this another way, the same number of workers could assemble 775% more automobiles in 1914. Looking only at final assembly overstates the productivity of the assembly

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32 Williams, et al. 1992.

33 Barclay 1936, 205.

line, however. Savings achieved in manufacturing individual parts were not as dramatic. On the other hand, the assembly line made monitoring individual worker performance easier. Responsibility for correct installation of each part was clear, and any slacking on the job quickly became a bottleneck in the flow of production. The assembly line also reduced the thousands of spare parts that once had been lying around as floating inventories and thus saved the capital previously tied up in un-assembled parts. Because assembly lines sped up production and reduced inventories, companies that adopted them had a competitive advantage. The Ford Motor Company initially was the only one with this new production technology, and it could simultaneously undersell its competition, raise wages, and yet increase profits.

OTHER FACTORS IN THE ASSEMBLY LINE'S EMERGENCE

Knowing what the assembly line became after it was invented does not explain why the Ford Motor Company developed this new manufacturing system in the first place. No master plan seemed to exist from the start, and no one imagined the final result. Rather, Ford managers and engineers were struggling to make cars fast enough to meet accelerating demand. They looked for efficiencies and discovered that simple changes in how workers moved or were positioned or received the materials they needed saved time. Along with these adjustments came subdivision of each job into many smaller tasks. For example, making a magneto took a single workman twenty minutes. The same task, subdivided and laid out along a moving line at the perfect height, could be done in only seven minutes. The idea of the assembly line seems to have emerged from such sub-assemblies of the more complicated individual parts. These lines fed into the larger production, which might be diagramed to look much like the skeleton of a fish, with all the lines leading into a central vertebra, where the cars were assembled.[34]

Yet it cannot be emphasized too strongly that the ultimate incentive for creating the assembly line was the apparently insatiable demand for the Model T itself. Had the public wanted only 50,000 new cars a year or less, then the many artisanal car manufacturers might have continued to serve that market. Mass production only made sense if there was mass demand. Ford not only understood this, he realized that he could stimulate demand by lowering the price. Against the advice of his own executives and stockholders, he continually reduced the price of the Model T, which in turn increased demand and made possible greater economies of scale in production. Eventually he bought out all the other stockholders, and no one could obstruct this policy. The price eventually fell to less than $300 for a new car in 1926.

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[34] On changes in scale, see Friedel 2007, 449-478.

Greater volume production not only required more factories, it required new kinds of factories, and the series of plants that Ford built in the two decades after he founded his company 1903 traces the transformation of architecture that accompanied changes in production. First came the 1904 Piquette Avenue factory, which resembled a nineteenth-century textile mill building. It was three stories high, about as long as a football field, including the two end zones, but only 12 meters wide. Built specifically for manufacturing automobiles, it nevertheless was obsolete in only five years, because it was suited to artisan laborers and the production of only a few thousand cars a year. By 1909 Ford was making 14,000 cars a year, and a larger facility with a different design was needed. The Highland Park plant was not designed with the assembly line in mind, as already noted, but it was far larger than the Piquette Plant. It was more open, facilitated materials handling, and provided electrical drive to all machinery. Here the assembly line was invented, incrementally, and production skyrocketed. In 1910-1911 it more than doubled to 35,000. The following year it rose to 78,000, and by 1913-1914, when the assembly line was being installed, 248,000 cars rolled off the line. In response, Ford built another factory complex at Highland Park, the first one built with the assembly line in mind. Biggs has rightly emphasized the importance of the 1914 Highland Park New Shop, as the first rational factory.[35] Completed in August, 1914, its two parallel buildings were each six stories tall, built with steel reinforced concrete. The New Shop was the full expression of the Ford assembly line. In the 1920s the Highland Park complex produced more cars every week than the Piquette Plant had been able to assemble during its best year.[36]

COMMON MISPERCEPTIONS

Two aspects of Ford's assembly line have at times been misunderstood. The first of these was the $5 day, introduced in 1914. This policy represented a doubling of what were then the ordinary wages of about $2.50. The Ford Company explained the higher wage as a form of profit sharing; they paid workers more because in return they were making the assembly line so efficient. But an important motive for the $5 Day was the desire to combat labor turnover that had risen to alarming levels by 1913. Higher pay encouraged workers to remain longer. Despite paying a higher wage, Ford profits rose in 1914 by $4 million, and increased in 1915 by additional $8.5 million to $40.3 million.[37]

These profits were achieved while prices fell. The Ford Motor Company lowered the price of the Model T by $50 in 1913 and $60 in 1914, even as wages increased. The price of a Model T fell from $950 to just $397 in 1921.[38] The higher wage and

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35 Biggs 1996, 118-136.

36 On factory design, see Lewis, 2001, 666.

37 Raff and Summers, 1987, S75.

38 Ford 1922, 145; Casey 2003, 51.

the falling cost of the Model T made it possible for Ford workers themselves to purchase automobiles. Ford understood that mass production logically required mass consumption. In 1910 one of his workers typically made $2.50 per day, and a $950 automobile cost 380-days' wages. In 1921 a new Model T cost only 80-days' wages. A used car cost even less.

Ford conceived of the $5 Day as the link between production and consumption in a single marketplace. When wages doubled, consumption could rise accordingly. In contrast, more recently American and European corporations have outsourced manufacturing to low wage nations in Latin America, Asia, or Eastern Europe. The mass production worker in the developing world is not often seen as a potential consumer, and corporations maximize profits by minimizing wages. In 1914 Ford might have done the same thing. Instead, he raised wages, increased productivity, and relentlessly drove down the price of his car in order to maximize the size of his market. By the early 1920s he was making half of the world's automobiles.

A second misconception regards the Model T itself, which is often seen as an unchanged vehicle from its introduction in 1908 until 15,000,000 had rolled out of the Ford factories in 1927. In fact, during the two decades of its production, the Model T underwent many changes. Notably, electric lights and an electric starter were added. The car's styling underwent modest changes as well. In all, "the Model T underwent thousands of detail changes,"[39] and it was a far better car in 1927 than it had been in 1908. If the focus remained on improving the manufacturing process the Ford car did change, despite popular mythology to the contrary. Some parts of the car changed little, and these were at the core of the Model T, notably the transmission, the magneto, the 4-cylinder engine, and the suspension system. But the product was hardly static. In 1913 alone Ford made more than 100 design changes every month in the parts that went into the car. As those who purchase and restore a Model T quickly discover, the general appearance may be much the same from 1912 until 1927, but the model year does matter. For example, the electrical system was completely redesigned twice. Alterations were scarcely emphasized but introduced piecemeal rather than ballyhooed in annual models. Most changes were scarcely visible to the average customer. Thus the Ford assembly line did not require that the car's design remain completely frozen, and it did incorporate improvements and small additions.

OTHER FORMS OF PRODUCTION

Many have confused the assembly line with Frederick Winslow Taylor's concept of scientific management. While both systems sought to rationalize work and improve efficiency, they were not at all the same. Taylor's system emerged first and focused on making worker movements more efficient. Instead of allowing workers to

[39] Casey 2003, 74.

decide how they wished to tackle a task, such as shoveling, he determined the ideal weight that a man could lift, and then designed specialized shovels for each task, so that a shovel for moving sawdust lifted a greater volume than one for lifting sand. Taylor also regulated work routines, telling men when and how long they should relax and specifying how much work they should do. He examined the movements of the most efficient workers, breaking them down into small sequences, Taylor determined "the best way" to perform a task and then retrained workers, so they could complete a job with the least possible effort and movement. To motivate workers to do more in the same time, Taylor relied upon incentives. There were normal wages for achieving a prescribed daily quota, with bonuses for exceeding the norm. Essentially, he modified the piece-rate system. Managers who worked in a similar spirit often used a stopwatch to establish how long each movement on every job should take. The scientific manager demanded that workers give up personal routines for standardized movements made with standardized tools and paid them according to an incentive system. Those who co-operated produced more. In return, Taylor expected employers to raise workers' pay, though not all corporations adopted this part of his system.

Taylor reorganized entire factories, but aroused strong worker opposition. Hugh Aitkin found that workers at the Watertown Arsenal prevented Taylorism from going into effect. They demonstrated that they knew more about their tasks than those who attempted to reformulate them.[40] Despite such setbacks, Taylor's ideas circulated widely. His book *The Principles of Scientific Management,* sold widely in French, German, and Russian translations, and Lenin praised it. "Taylorism" had an enormous resonance beyond the factory in many areas, including home economics, education, and popular culture. Experts appeared in every area of life, proclaiming that they had discovered the "one best way" to arrange a kitchen, regulate traffic flow, or plan a community.

Nothing could be further from Ford's assembly line. Taylor designed ideal tools, such as different shovels for materials of different weight. Ford Motor Company abolished shoveling itself, in favor of electric cranes, moving belts, and other aids to continuous flow manufacturing. Taylor retrained a worker to do the same job more efficiently; the assembly line redefined and simplified jobs. Taylor offered workers incentives to do piecework more quickly; Ford made piece rates pointless, because the assembly line paced the work, pushing everyone on the line to move at the same speed. Instead, workers received a high fixed wage. Taylor maximized efficiency in existing production technologies; Ford transformed the means of production. Taylor saved time; Ford sped up time. In 1914, after Taylor put his system into operation at the Packard Motor Company, its 4,525 workers produced 2,984 cars a year. That was an annual production of only two-thirds of an automobile for each employee. This

[40] Aitken 1960, 268-271; Haber 1964.

was still fabrication with artisan methods. In precisely the same year, 13,000 Ford employees, using conveyor belts, electric cranes, and 15,000 specialized machine tools, manufactured 260,000 cars, or twenty vehicles per man. Ford workers outperformed those Taylor organized by three thousand percent. In just four days they assembled more automobiles than Packard constructed in an entire year. Taylor had maximized what was possible in the older artisan tradition. The assembly line was still in its infancy, and it had the potential to become far more productive. Often, people measured the productivity of the assembly line not by output per worker, but rather by how fast the cars were made. Before the assembly line, Ford workers used more than 12.5 hours (750 minutes) to assemble a car. Once the assembly line went into operation, it took less than 100 minutes.[41]

Because the manufacturing systems of Taylor and Ford differ so sharply, some historians have contended that they represent two distinct historical stages, “Taylorism” and “Fordism”. Implicit in such arguments is the idea that manufacturing as a whole evolves through distinct historical stages. However, Phillip Scranton has shown that this approach to manufacturing does not square with the complexity of historical fact. Rather than focus on large corporations such as Standard Oil, General Motors, Ford, and DuPont as the most advanced form of capitalism, in *Endless Novelty* Scranton examined firms with customized and small batch production. Far from being unprofitable businesses destined to be converted to Taylorism before adopting assembly lines, such companies remained financially successful, and they proved just as important to an advanced economy as mass production. Companies fabricating elevators, turbines, switchboards, and precision instruments did not “fail” to become mass producers. Nor did they want to deskill labor. Rather, they prized skilled workmen who could respond flexibly to demand for varied goods. Such workers made possible the endless novelty that was the hallmark of the consumer society, and such companies were innovative and profitable. Fredrick Winslow Taylor’s prescriptions were useful for repetitive movements for the production of identical things, but not for batch production of fine carpets, furniture, jewelry, cutlery, hats, and ready-to-wear clothing. Consumers wanted variety, and large profits accrued to flexible firms with skilled workers that could supply endless novelties. Assembly lines were suited to making identical things, but many products of advanced technology had to meet customer requirements for installation at specific locations, and in the department stores customers wanted variety and novelty.

Specialty production was not a sideshow. It grew just as fast as mass production, but it did so with different central actors. Instead of the “visible hand” of corporate managers advised by scientific experts, at the centre were skilled workers and technologically adept owners. When it suited them, they drew on new work systems,

41 Nevins and Hill 1964, 474.

of which Taylorism was only one. Instead of the rigidity of Taylor's "one best way," they valued flexibility. Instead of standardization of production at capital-intensive plants, they fostered diverse production at labor-intensive mid-sized factories, and these proved to be technologically innovative. In short, industry as a whole did not move through stages from artisan production to "Taylorism" to "Fordism." There was no single path for successful corporate development. Rather, the assembly line was ideal for long runs of identical goods, but specialty production was ideal for higher end products that were distinctive and it could change rapidly to meet the demands of fashion. Likewise, large complex machines such as steam locomotives, elevators, switchboards, and the like had to be crafted to meet the needs of particular buyers. They were never produced in the numbers required to justify setting up an assembly line. Instead of a single path to development, there were many.

Nevertheless, the assembly line was extraordinarily productive compared to the craft labor assembly of cars that preceded it. Daniel M. G. Raff examined the Ford records from these years, and after making adjustments for changes in raw material prices and the cost of living, concluded that Ford was an extraordinary company compared to the rest of American industry between 1909 and 1914.[42] Its annualized productivity growth was an astounding 22%, compared to 1.5% in the economy as a whole. Many industries were almost stagnant, with productivity growth at less than 1%, including electrical machinery, durable goods, and textiles. Some entire industries actually became slightly less productive between 1909 and 1919, including chemicals, furniture, and primary metals. Clearly the assembly line broke these patterns dramatically, and the productivity increases continued during the 1920s.

CONCLUSIONS

Defining the elements of the assembly line and demonstrating how it was different from Taylor's scientific management does not explain how the assembly line came into being. The process of breaking down conventions, of throwing out inherited work routines, of building new equipment and arranging it in new ways, demanded a special atmosphere of experimentation and an exceptional openness to change. Just because the elements of the assembly line were all available does not mean that they would necessarily be combined. Had Ford behaved like all the other automobile manufacturers in 1910, his cars would have required more hours to make and cost the consumer more to buy. He would still have made a good deal of money. What drove the team of managers at Ford was not only profits but also a vision of accelerated production and efficiency that became an end in itself. In their own way they briefly created a dynamic process of discussion, feedback, and continual improvement much like that designed into the lean production system created in

42 Raff 1996, 183.

Japan several generations later. This dynamic carried over from Highland Park to the creation of the River Rouge Plant, which was built around the Ford Motor Company's evolving understanding of the most efficient form of an assembly line. Rather than give the credit to Henry Ford himself for these developments, it is more accurate to say that he was the fortunate beneficiary of synergies among the exceptionally talented people he recruited. Ford gave those willing to buck conventions and try out new things the incentive and the authority to do so. In retrospect, something like the assembly line might seem the inevitable result when strong consumer demand stimulated managers to look for more efficient manufacturing methods. But the assembly line could have emerged later, or somewhere else, making another product. It conceivably could have emerged sooner, perhaps in France where the goal of interchangeable parts was briefly pursued in the late eighteenth century.[43] But technological innovations are not always remembered and therefore do not always accumulate. As Adler has emphasized "a technology (even a technology today accounted superior) can be rejected, discontinued, and forgotten."[44] This happened to the achievement of interchangeable parts production in France, where Napoleon reverted to the artisan production of the *ancien regime*.

In contrast, once the assembly line was up and running, it most certainly was not forgotten, but it has often been oversimplified and "mis-remembered." Much of the cost savings achieved at the Ford Highland Park factory were not due to the introduction of the moving line itself, but resulted from efficiencies realized through subdivision of labor, improved accuracy in making interchangeable parts, rearrangement of machinery, and better work-flow layouts in an electrified factory. More importantly, the assembly line is best understood not as a rigid system, nor as an imagined historical stage called "Fordism" following an equally imaginary "Taylorism." Rather, the assembly line was (and is) an evolving processing technology that has become more efficient during the century since its invention. In this perspective, "post-Fordism," "lean production" and "post-lean production" are not new historical stages, but rather improved assembly lines. The abolition of "Fordism" as a historical stage and its de-coupling from "Taylorism" brings more complexity to corporate and labor history. It also awakens interest in specialized and flexible production systems that have coexisted with the assembly line from 1913 until the present. This redefinition of the assembly line does not deny that mass production workers were deskilled and often exploited. Rather, it discloses the contribution workers could have made to increasing efficiency and quality at an earlier date, if given the chance, as they eventually were in Japanese corporations.

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[43] Adler 1997, 297-300.

[44] Ibid., 310.

To see how and why these discoveries matter, a sketch of subsequent events is useful, even if detailed exploration of these matters cannot be undertaken here.[45] The creativity that led to inventing the assembly line was not sustained in the United States after the mid-1920s, as industry became "path dependent," and no longer made many incremental improvements of the sort that had led to its discovery.[46] Instead, annual product design changes became paramount to convince consumers that their vehicles were becoming obsolete.[47] American corporate managers also became fascinated with automation after World War II. From the 1950s until the 1970s, with extensive support from the Defense Department, research and development efforts focused on creating computer controlled assembly lines staffed by robots that could replace workers and operate around the clock.[48] These investments resulted in few actual robots, however, as in the 1970s 99% of factory work continued to be done by human beings.[49] The automation campaign further alienated workers, whose absenteeism and turnover had become "normal" in assembly line manufacturing by the 1970s.[50] Labor's disaffection made it difficult for American corporations to adopt the lean production system and catch up with the Japanese manufacturers in the 1980s and 1990s, for "lean" companies rely on close cooperation between teams of workers and management.[51] Hundreds of thousands of American jobs were lost to competing European and Japanese manufacturers. Indeed, by the 1990s the Japanese automakers were producing more than 2 millions cars a year inside the US.

Sketching this larger history further emphasizes that "Fordism" was not a technologically driven historical stage but rather a socially constructed form of production that became deeply rooted in American mass production industries. Because the assembly line was a key element in US prosperity between 1914 and 1974, Americans naturalized it as the best way to manufacture. The resulting corporate path dependency long blinded US managers to further improvements. They imagined, much like neo-Marxist historians, that the assembly line was a definite stage, rather than one moment in a fluid and ongoing process of development. They imagined that automation was the next stage. As often happens with process innovation, an outside group with a fresh perspective, in this case the Japanese, saw that automation was not the most efficient way forward. They discovered that the assembly line could be vastly improved, doubling productivity with little investment in new machinery while actually reducing the number of workers. In short, not

45 The years from c. 1920 until 2013 will be treated in my centennial history of the assembly line, MIT Press, 2013, forthcoming.
46 Utterback 1994, 145-166 and passim.
47 Slade 2006, 45.
48 Weiner, 1950, 154-159, passim; Noble 1984, chapters 1 and 2.
49 Simpson 1980.
50 Compare Faunce 1962 with Aronowitz 1973 and Sandler 1982.
51 Shimokawa 1993; Kenney and Florida 1993; Ortiz 2006.

only was the assembly line the outcome of a century of increasing efficiency before 1913, it was also the beginning of further efficiency improvements that still are accumulating.

In this light, the American assembly lines in Mexico, mentioned at the start of this essay, are not the future, but the past. They are a short-term strategy that allows American corporations to postpone conversion to lean production, substituting cheap labor on classic assembly lines for more expensive but more innovative multi-skilled labor on flexible lines. Indeed, during the last fifteen years, lean production itself has already been surpassed, as "post-lean production" has cut automobile assembly time by a further 50%.[52] Each "stage" is barely named before being surpassed by further process innovations. The assembly line in 1913 was neither a beginning nor an end, but rather part of a long series of innovations that began at least two centuries ago. As the classic Ford line approaches its centennial in 2013, the pace of this change is not slackening but accelerating.

52 Wilson 2000; Maynard 2003.

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ABSTRACT

The Ford assembly line of 1913 was part of a long series of process innovations that began a century before and that have continued since, notably in the lean production system. This paper examines the historical emergence and synthesis of the five essential elements of the classic assembly line – sub-division of work, interchangeability, single-function machines, organization of machines according to the sequence of assembly, and moving work to the worker, typically using gravity slides or moving belts – and further shows that full electrification was an essential precondition for its creation and proper functioning. In contrast, "scientific management" was not important to the creation of the assembly line.