

# Mr. Taylor, Mr. Ford, and the Advent of High-Volume Mass Production: 1900-1912

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**Abstract:** While most management professionals recognize the names of Taylor and Ford, they do not realize the unsung connection between the two men and the import of this connection to high-volume mass production (HVMP). Taylor is best known for his work with scientific management; however, it was Taylor and his research group at Bethlehem Steel that made the critical discovery that made interchangeable parts possible. Ford used this advance to fuel the advent of HVMP; this jump occurred several years before Ford's use of moving assembly lines. This paper argues that it is neither "scientific management" principles nor moving assembly lines that most intimately conjoins Taylor and Ford; it is Taylor's work as a mechanical engineer and Ford's use of that work.

## Introduction

Biographers of Ford spend time and effort discussing the possible impact of Frederick Taylor's "Principles of Scientific Management" and "Shop Management", and "efficiency engineering" in general, on Henry Ford's practices in Model T design and production. For example, Hounshell<sup>1</sup> spends five pages on this discussion and Brinkley<sup>2</sup> spends two. Most sources agree that the two were pursuing different goals with different strategies, and that, overall Taylor's work had little effect on Ford's processes and factory design.

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<sup>1</sup> Hounshell, David A. *From the American System of Mass Production, 1800-1932*. Baltimore, MD: The Johns Hopkins University Press, 1985, pps. 249-253.

<sup>2</sup> Brinkley, David. *Wheels for the World: Henry Ford, his company, and a century of progress*. New York: Viking Penguin, 2003, pps. 139-140.

This paper argues that Taylor did indeed have an enormous effect, not only on Ford Motor Company processes, but on manufacturing processes throughout the world - effects that had nothing whatever to do with scientific management. This paper argues that Taylor's work with high-speed steel research at Bethlehem Steel in the late 1890s resulted in revolutionizing the machine tool industry, that this revolution made interchangeable parts both possible and economical, and it was this revolution that placed in Henry Ford's hands the technology to establish and then revolutionize high-volume mass production.

Producing objects in volume had long been a dream of manufacturers. However, the lack of tools, technology, and knowledge prevented this from becoming a reality until the nineteenth century. Even with the evolution of the "armory" or "American system" of manufacturing, true mass production was impossible; if it was manufactured, it still required hand-finishing by one using craft production techniques. Even to the close of the nineteenth century, "mass production" meant that some work was done by machines, to be finished by hand, especially relative to manufacturing metal goods.

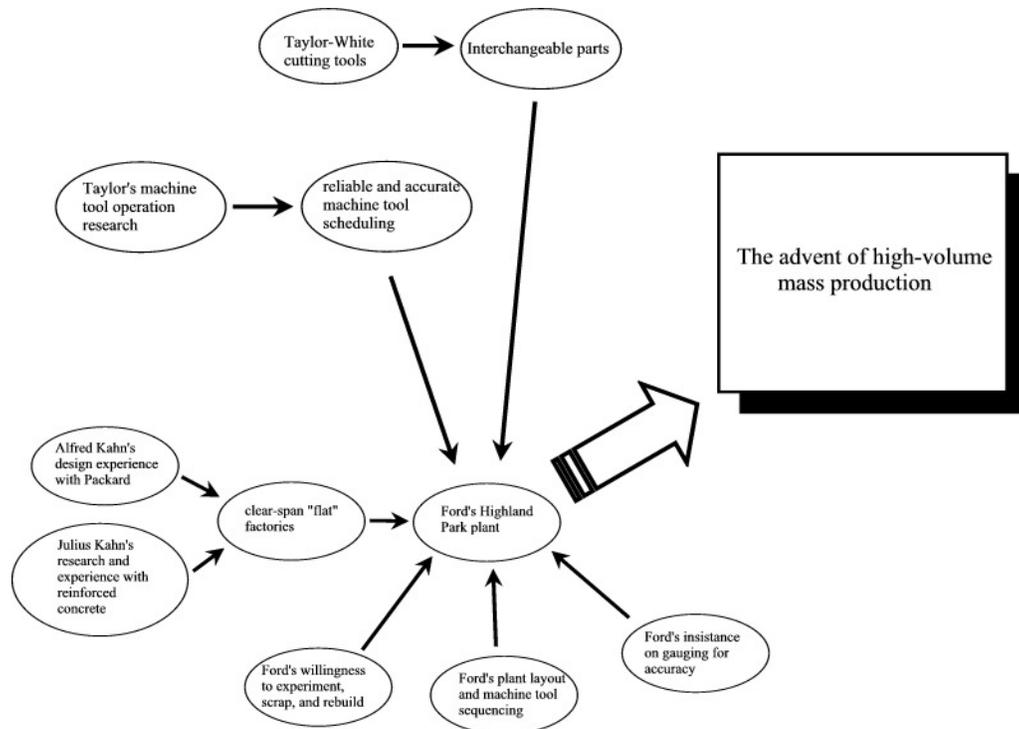
The crux of the problem was manufacturing identical, interchangeable parts on an economical basis. Prior to 1900, the choice was between interchangeable parts and economy; you could have one, but not both. If you chose "interchangeable parts", the degree of hand-finishing, called "fitting" called for expert hand filing to gauge. To choose "economy" still called for hand-fitting, but to a much lesser degree than that required for interchangeability. The solution to this problem was discovered through direct experimentation by Frederick Taylor and his assistants. In turn, Taylor's work in Bethlehem Steel's Machine Shop #2 led to innovations that gave Henry Ford the necessary tools to realize his vision of "everyman's car." The astounding thing is that all of this work by both Taylor and Ford took place before the events with which these men are most identified - Taylor's "scientific management" and Ford's moving assembly line. Further, these accomplishments are arguably more important than their "trademark deeds." The integration of these points is shown in Figure One.

### **Realizing the need for parts interchangeability**

The first widely-reported instance of interchangeable parts in Western history is mid-fifteenth century, with the advent of Gutenberg's movable type. Actually a segment of a three-part system, movable type contributed markedly to both the Renaissance and the Reformation. Gutenberg's genius was combining the idea of movable type, the use of oil-based ink, and a wooden printing press adapted from olive and fruit presses; in doing so, he made printed matter less expensive, just as inexpensive paper was becoming available. This triggered a surge in literacy as printed material - tracts, pamphlets, and broadsides in addition to books – became more easily and cheaply available; further this literacy was not just limited to the upper classes, but was much more widespread throughout the population.<sup>3</sup>

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<sup>3</sup> Burns, Edward M. *Western Civilizations: their history and culture* (6 ed). New York: W. W. Norton and Company, 1963, p. 386.



**Figure One: The integration of Taylor's and Ford's work**

Between the mid-fifteenth century and the beginning of the eighteenth century, Europe was plagued by a series of regional wars. Increasingly, these wars were fought with firearms, artillery as well as musketry. This led to a production paradox: at the same time that demand was growing, firearms were in scarce supply. They were therefore (1) militarily important, and (2) very expensive - expensive to obtain, expensive to use, and expensive to maintain. Built by hand by expert gunsmiths, they were expensive to obtain. Used only by the very wealthy, they were expensive to use because of all the material required (matchstock giving way to flints, gunpowder, shot, etc.). If they malfunctioned or broke, which happened very often, they were expensive to repair, new parts having to be made by those very same gunsmiths who fabricated firearms in the first place.

It was this confluence of events - military need and scarcity/expense - that made the firearms industry one of the first to launch a concerted search for the "grail of interchangeability". Interchangeable parts would reduce the expense of manufacture, the expense of use and the expense of repair.

One additional factor further complicated this problem. The size of armies was continually growing throughout this period. By the end of the eighteenth century, both military and naval services of major powers were large, even by modern standards. This made the demand for firearms even larger, but little progress had been made in the search for techniques that would allow inexpensive yet precise replication of identical parts.

And this is precisely the problem. Manufacturers had known for some time both (1) what needed to be done and (2) how to do it. It was not replicating identical parts that was the

problem. The problem was to do this economically. Parts interchangeability was certainly possible, but was most certainly not economical.

### The primary problem

The literature on interchangeable parts never states and seldom approaches the critical problem. While the literature talks much about the advantages of parts interchangeability, and the trials of inventors, innovators, and manufacturers in reaching true interchangeability, the closest the literature comes to defining the critical problem is to state that essentially the parts could not be made to fit without hand-filing. Hounshell comes the closest to pinning down the critical technology when he states:

"The process of hardening parts made interchange impossible because iron always changed its shape during and after this process (parts were worked or machined in a soft state and then hardened for their final use). Even if parts fitted together nicely before hardening, they would not do so after it. They had to be 'restored.' The eminent machine tool builder and master of precision (Joseph Whitworth - JP) argued that this could be done 'only by hand labour [sic].' "<sup>4</sup>

Certainly, it has been established that the machine tools were available at this time. (For those unfamiliar with "machine tools", Rosenberg defines them as, ". . . machine tools shape metal through the use of a cutting tool and the progressive cutting away of chips . . ." <sup>5</sup> This includes lathes, drill presses, milling machines and so on.) Simply put, machine-tool cutting edges simply were not hard enough to machine previously-hardened steel. Therefore the steel was worked/formed/forged/machined and then put through the hardening process which involves heating and quenching (cooling in water or oil) or air-cooling, thereby warping the piece to the extent that it needed reworking - "restored" in Whitworth's words <sup>6</sup> - by hand before it was usable. The choice then was binary: Leave the steel as "mild steel" in which case it would be too soft to properly perform its function, or "hand fit" the part after hardening (requiring lengthy filing by expert craft masters). In the only reference this writer has seen stating this explicitly, Womack et al. (1990) say, "The warping that occurred as machined parts were being hardened had been the bane of previous attempts to standardize parts."<sup>7</sup> This came from a book about contemporary lean manufacturing, not any writing about history of technology; therefore, it is unlikely that a technology historian would stumble across this.

This is the reason interchangeable parts did not become a reality in the 1880s. With reference to early breech-loading rifles in 1853, Gordon states, "Since all the surfaces that had to be brought to gage [sic] dimensions in these rifles were hand-filed, it follows that the machine tools used in making these parts were not capable of the accuracy needed to attain a

<sup>4</sup> Hounshell, p. 23.

<sup>5</sup> Rosenberg, Nathan. "Technological Change in the Machine Tool Industry, 1840-1910." *The Journal of Economic History*, volume 23, Number 4 (December, 1963), p. 417.

<sup>6</sup> Hounshell, p. 23.

<sup>7</sup> Womack, James P., Daniel T. Jones, and Daniel Roos. *The Machine that Changed the World: The story of lean production*. New York: HarperPerennial, 1990, p. 27

close fit of the breech mechanism and interchangeability of parts."<sup>8</sup> In other words, although the machine tools were present, they were not yet precise enough. Therefore, the second problem - that of producing the capability of *precision* machining - was still unsolved in the 1800s.

Therefore, the primary problem definition is this: To achieve parts interchangeability, manufacturers need to have the capability to machine parts *after* they have been hardened. Womack et al. further refined this definition: "The key to interchangeable parts . . . lay in designing new tools that could cut hardened metal . . . with absolute precision. But the key to *inexpensive* interchangeable parts would be found in tools that could do this job at high volume with low or no set-up costs between pieces."<sup>9</sup> (emphasis in the original). This latter statement acknowledges the pressure toward incipient mass production at the turn of the century.

### Ensuing Secondary Problems

Beyond cutting tools that kept their edge, there ensued other critical problems with which to deal. As Nelson (1980) puts it, "To take full advantage of the new tools, it was necessary to redesign the machines in which they were used."<sup>10</sup> In other words, contemporary machine tools in 1900 were not capable of taking full advantage of the new cutting edges. There were four important requirements for redesign; the machines had to be made (1) heavier so they would not shift or change position with higher cycle times, faster feed rates, and deeper cuts, (2) more rigid for the same reason, (3) be automated for higher volume of production than ever before, and (4) be capable of more precise speed control to take advantage of the new "slide rules" that were capable of calculating optimum feed, speed, power and machine time settings.<sup>11</sup>

These redesigned machines were important for (1) producing the parts in volume, and (2) producing the machines capable of doing this.

However, knowing how to make interchangeable parts did not mean that those interchangeable parts were economical; the Springfield Arsenal demonstration was in the late eighteenth century, and hand-forming and -fitting precision parts was anything but economical<sup>12</sup>. To become economical, the parts had to be machine-made.

In this case, "machine-made" means something even more specific. "Machine made" has to mean "in high volume." The machinery itself is a large capital expense, contributing to overhead. In order to economically buy, install, and use such machinery requires enough volume from the machine to cover its overhead, in order to reduce the average cost per part; in other words, the part has to be made in a high enough volume to let economies of scale obtain. Further, to manufacture this volume, the machinery has to be automatic, i.e., completing a sometimes complex series of operations and stopping itself when this set of operations is

<sup>8</sup> Gordon, Robert B. "Simeon North, John Hall, and Mechanized Manufacturing." *Technology and Culture*, Volume 30, Number 1 (January, 1989), p. 185.

<sup>9</sup> Womack, p. 35.

<sup>10</sup> Nelson, Daniel. *Frederick W. Taylor and the Rise of Scientific Management*. Madison, WI: The University of Wisconsin Press, 1980, p. 87.

<sup>11</sup> Nelson, p. 88

<sup>12</sup> Hounshell, p. 4.

complete. This latter condition - automation - is necessary in the interest of speedy production, to free the machine for making the next part.

The design techniques for weight, rigidity and automation were met between 1850 and 1880. Smith documents an antebellum vertical milling machine which ". . . not only functioned without any manual guidance but evidently ceased operation once the workpiece had been finished." These machines required ". . . no mechanical skill so that any reasonable alert individual could learn the job within a relatively short period of time."<sup>13</sup> This means that no (expensive) skilled machinist is required. Smith also documents automatic machinery for profiling gunstocks. He continues, "Featuring solid metal construction, formed cutting tools, variable speed control, and automatic stop mechanisms, Hall's cutting machines represented a significant step forward in milling iron."<sup>14</sup> Therefore, there is ample evidence that machine tools and automation existed in quality and quantity prior to the 1880s.

Only by using automated machine tools could enough parts be completed to become economical for everyday use. Woodbury (1960) states, "...modern interchangeable parts require these elements: (1) precision machine tools, (2) precision gauges or other instruments of measure, (3) uniformly accepted measurement standards, and (4) certain techniques of mechanical drawing."<sup>15</sup> By the late nineteenth century, all of these elements were present. Both Smith<sup>16</sup> and Gordon<sup>17</sup> relate the presence of precision gauges and measures, and Hounshell<sup>18</sup> shows the availability of machine tools – drop forges, milling machines, turret lathes, screw machines, grinding machines, drilling machines, and boring machines – by the 1880s.

Relative to Woodbury's requirements, there was still the drafting problem. Referring to the ". . . techniques of mechanical drawing"<sup>19</sup>, Brown (2000) describes the development of precision drafting in the United States and compares these developments in drafting and engineering to those in Great Britain in the same era<sup>20</sup>. Because of centuries-old apprenticeship programs reaching back to medieval guild practices, Europe and the United Kingdom had no shortage of skilled machinists for contemporary manufacturing; these skilled artisans could be shown a rough model or rough, essentially dimensionless drawing and still turn out an acceptable part that would work. However, the United States had suffered a shortage of skilled labor since its inception; in order to gain a usable part with "home grown" skilled labor, it needed to be drawn or modeled with precision so that the machinist could produce or copy it. This led to mechanical drawings of much higher precision in the United States than in the United Kingdom, beginning in the early 1800s. This fulfills the fourth of Woodbury's requirements.

<sup>13</sup> Smith, Merritt R. "John H. Hall, Simeon North, and the Milling Machine: the nature of innovation among antebellum arms makers." *Technology and Culture*, Volume 14, Number 4 (October, 1973), p. 582.

<sup>14</sup> Smith, p. 583

<sup>15</sup> Woodbury, Robert S. "The Legend of Eli Whitney and Interchangeable Parts." *Technology and Culture*, Volume 1, Number 3 (Summer, 1960), p. 247.

<sup>16</sup> Smith. p. 583.

<sup>17</sup> Gordon, p. 180-181.

<sup>18</sup> Hounshell, p. 194.

<sup>19</sup> Woodbury, p. 247.

<sup>20</sup> Brown, J. K. "Design Plans, Working Drawings, National Styles: engineering practice in Great Britain and the United States." *Technology and Culture*, Volume 41 Number 2 (April, 2000).

## The solution

By the 1890s, then, there were two problems unsolved: the cutting tools and the precision speed control. The solution came in two sequential parts. First, the tool steel used to make cutting tools in use in the late 1800s had been developed in 1868 by Robert Mushet in England. It was a steel alloy containing 2% carbon, 2.5% manganese and 7% tungsten. This formulation had the major advantage that it air-hardened rather than requiring quenching (rapid cooling by placing the part into a vat of oil or water, which increased the probability of warping). In 1898, the manganese was replaced by chromium.<sup>21</sup>

In 1894, Taylor began a series of experiments on cutting tools in the Cramp shipbuilding firm<sup>22</sup>. Later, continuing these experiments, he was less interested in cutting tools per se than he was in decreasing or eliminating the variability in the machining processes in Bethlehem Steel's Machine Shop #2, the shop he supervised<sup>23</sup>. This is explained by Brown's hypothesis on the divergence of the engineering cultures of the United Kingdom and the United States starting about 1860. Brown (2000) says, "By the 1870s, the Americans . . . shifted to using dimensional plans (i.e., mechanical drawings -JP) as a production-control instrument, to subdivide work and thus shift the balance of power over production from workers to engineer-managers. Their British counterparts seldom pursued this explicitly political goal with comparable vigor."<sup>24</sup>

Further, Brown specifically states, "Men such as . . . Frederick Taylor sought this control to achieve autonomy for the engineering profession and to increase business profits."<sup>25</sup> Nelson, in his biography of Taylor, states, "Control of the metal-cutting machinery, the most elusive element in the machine shop environment, was within his grasp."<sup>26</sup>, implying that it was control, not metal cutting, that was Taylor's ultimate objective. In addition, after the cutting tool steel process was perfected, Taylor further experimented with this machining to obtain optimality (see below).

In 1898, Taylor continued his investigation at Bethlehem Steel, aimed at finding a better steel-making process from which cutters may be made<sup>27,28</sup>. The problem with Mushet steel was that cutters made from it heated as they cut and consequently lost both their temper (hardness) and their edge; a steel more tolerant of heat was needed. A new hire, J. Maunsell White III, joined Bethlehem Steel and was assigned to Taylor as an assistant in these experiments. The two complemented each other well<sup>29</sup>, and as Neck et al. describe, "Just eight days after White joined the experiments (23 October 1898), discovery of the high-speed steel

<sup>21</sup> High Speed Steel. (n.d.) <http://en.wikipedia.org/wiki/>

<sup>22</sup> Nelson, p. 57.

<sup>23</sup> Nelson, p. 88.

<sup>24</sup> Brown, p. 199.

<sup>25</sup> Brown, p. 218.

<sup>26</sup> Nelson, p. 88.

<sup>27</sup> Nelson, p. 86.

<sup>28</sup> Taylor, Frederick W. *The Principles of Scientific Management*. New York: Harper and Brothers Publishers, 1914, p. 104.

<sup>29</sup> Neck, Christopher P. and Arthur G. Bedeian. "Frederick W. Taylor, J. Maunsell White III, and the Matthew Effect: the rest of the story." *Journal of Management History*, Volume 2, Number 2 (1996), p. 22.

techniques, which later produced the Taylor-White patents, occurred."<sup>30</sup> Essentially, these experiments proved that heating the alloys, such as the Mushet steel, to a much higher point (300°-400° F. higher, <sup>31</sup>1890° F.<sup>32</sup>), than previously used, coupled with conventional quenching techniques, produced a much harder steel. In essence, the cutter became harder the faster it cut (i.e., the higher the feed rate was), just the reverse of Mushet steel. Kirby et al continue, "Machine-tool practice was thus revolutionized, and speeds were doubled, tripled, and even quadrupled."<sup>33</sup> Wikipedia states, "The Taylor-White process was patented and created a revolution in the machining industries, in fact necessitating whole new, heavier machine tool designs so the new steel could be used to its fullest advantage."<sup>34</sup> In other words, the machine tools themselves, e.g., lathes, became both even heavier (both Smith and Gordon speak of solid metal (i.e., no wooden components) milling machines,<sup>35,36</sup> and more rigid machinery<sup>37,38</sup>, allowing for both greater accuracy and greater precision when machining parts. Further, the new steel allowed cutting previously-hardened parts. This means that parts could be machined **after** heat-treatment, negating any warping, on machines that formed with greater accuracy and precision. In an article in *Railroad Master Mechanic*, an anonymous staff writer reported that a cutter made of Taylor-White steel alloy on a lathe took sixteen minutes at an increased feed rate, used dry (i.e., no cutting lubricant), to form a certain test piece; at the end of this trial the cutter was unimpaired and still sharp. A cutter of Mushet steel was used in the same trial was took 23 seconds to burn out completely<sup>39</sup>. Another contemporary account may be found in *The Metallographist*<sup>40</sup>.

Further, upon development of the cutting-tool steel, more experimentation by Taylor, a mathematician named Knox, Henry Gantt (of "Gantt Chart" fame, one of Taylor's assistants) and Carl Barth (another of Taylor's assistants) resulted in the invention and manufacture of a slide rule<sup>41</sup> and "improved procedures"<sup>42</sup> for setting up and accomplishing lathe work in June of

<sup>30</sup> Neck et al., p. 22.

<sup>31</sup> Nelson, p. 86

<sup>32</sup> Neck et. al., p. 24

<sup>33</sup> Kirby, R. S., A. B. Withington, A. B. Darling, and F. G. Kilgour. *Engineering in History*. New York: McGraw-Hill, Inc., 1956, p.511; quoted in Neck et. al, p. 24.

<sup>34</sup> High Speed Steel. (n.d.) <http://en.wikipedia.org/wiki/>

<sup>35</sup> Smith, p. 583

<sup>36</sup> Gordon, p. 181

<sup>37</sup> Hounshell, p. 232

<sup>38</sup> Gordon, p. 181.

<sup>39</sup> *Railroad Master Mechanic*, Volume 24 (1900), p. 527. Accessed at [http://books.google.com/books?id=YSU2AAAAIAAJ&pg=PA527&lpg=PA527&dq=Railroad+Master+Mechanic,+1900+and+the+taylor-white+source=bl&ots=W0o7FtQz6A&sig=LVi4KAF\\_7QEsFLn7F0g58XCMCGA&hl=en&ei=7WFsS\\_mpBortAP21OWyDQ&sa=X&oi=book\\_result&ct=result&resnum=1&ved=0CacQ6AEwAA#v=onepage&q=&f=false](http://books.google.com/books?id=YSU2AAAAIAAJ&pg=PA527&lpg=PA527&dq=Railroad+Master+Mechanic,+1900+and+the+taylor-white+source=bl&ots=W0o7FtQz6A&sig=LVi4KAF_7QEsFLn7F0g58XCMCGA&hl=en&ei=7WFsS_mpBortAP21OWyDQ&sa=X&oi=book_result&ct=result&resnum=1&ved=0CacQ6AEwAA#v=onepage&q=&f=false), February 5, 2010.

<sup>40</sup> *The Metallographist*. Volume 6, Number 2 (April, 1903), p. 130. Accessed at [http://books.google.com/books?id=1voCAAAAYAAJ&pg=PA130&lpg=PA130&dq=the+metallographist+and+the+taylorwhite+process&source=bl&ots=6Ac46iild7&sig=oD4Bzx0NORa94buysmBP6xvbFgc&hl=en&ei=NWBsS6vbEzT4sQQepOWxDQ&sa=X&oi=book\\_result&ct=result&resnum=1&ved=0CacQ6AEwAA#v=onepage&q=&f=false](http://books.google.com/books?id=1voCAAAAYAAJ&pg=PA130&lpg=PA130&dq=the+metallographist+and+the+taylorwhite+process&source=bl&ots=6Ac46iild7&sig=oD4Bzx0NORa94buysmBP6xvbFgc&hl=en&ei=NWBsS6vbEzT4sQQepOWxDQ&sa=X&oi=book_result&ct=result&resnum=1&ved=0CacQ6AEwAA#v=onepage&q=&f=false) on February 5, 2010.

<sup>41</sup> Nelson, p. 85.

<sup>42</sup> Nelson, p. 88.

1899. In Nelson's words, they "... devised an improved procedure for calculating the appropriate speed, feed, power, and machine times for machine tool operations . . . By the end of the year he had prepared slide rules for thirteen of the largest lathes in Machine Shop No. 2. Taylor was ecstatic. At last he had a way to determine proper machine tool methods. Control of the metal-cutting machinery, the most elusive element in the machine shop environment, was within his grasp."<sup>43</sup>

It is then quite likely then that these innovations passed rapidly throughout the machine-shop community. Smith writes, "In a society lacking adequate educational facilities, professional associations, and technical publications, a great deal depended upon the personal transmission and dissemination of mechanical ideas. Time and again factory masters received valuable assistance from itinerant mechanics. Time and again those same mechanics carried away know-how and placed it at the disposal of others."<sup>44</sup> Of course, Smith was speaking of "machine-shop culture" in the 1850s and 1860s, but I suggest that the machine-shop culture was little changed, but was on the verge of change, in the 1890s. In addition, Taylor was active in mechanical engineering circles, publicizing the Taylor-White process, and Taylor and White were awarded the Elliott Cresson Medal by the Franklin Institute in 1902; Taylor was given an award for the same accomplishment at the Exposition Universelle Internationale in Paris in 1900<sup>45</sup>. All of these helped increase the visibility of the Taylor-White process.

The first of the keys to interchangeable parts was present at last.

The second and final part - precision speed control - quickly followed. At this time (i.e., circa 1900), machine tools were driven by a central power source, usually a steam engine. The steam engine turned a large, central drive line, equipped at regular intervals with large pulleys. These pulleys were in turn connected to the machine tools by a wide leather belt. This system is known as a "line-shaft, belt-drive" system; Biggs has a particularly interesting photo of such a machine shop<sup>46</sup>. Devine describes speed control on such a system: "To run any particular machine, the operator activated a clutch or shifted the belt from an idler pulley to a drive pulley using a lever attached to the countershaft. Multiple pulleys offered speed and power changes."<sup>47</sup> Obviously, such a system was variable only in discrete increments, as one changed from a larger to a smaller pulley or vice versa; intermediate speeds were impossible, except by the addition of more pulleys. Such a system negated some of the advantages of Taylor's research on optimum speed and feed rates. However, by this time, this was becoming easier to fix. The answer lay in the transition from line-shaft/belt-drive power transmission to "unit motors", i.e., machines driven by individual electric motors, supplied (then) by on-site-generated DC electricity. Speed control was easily achieved on these motors by known technology (e.g., variable resistors or potentiometers.)<sup>48</sup> Thus was the second major consideration solved.

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<sup>43</sup> Nelson, p. 88.

<sup>44</sup> Smith, p. 591.

<sup>45</sup> Neck et al., p. 24.

<sup>46</sup> Biggs, Lindy. *The Rational Factory: architecture, technology and work in America's age of mass production*. Baltimore: The Johns Hopkins University Press, 1996, p. 84.

<sup>47</sup> Devine, Warren, D. Jr. "From Shafts to Wires: historical perspective on electrification." *The Journal of Economic History*, Volume 43, Number 2 (June, 1983), p. 352.

<sup>48</sup> Devine, p. 366.

By 1901, therefore, both the cutting tool and precision machining problems were solved.

### **The effects: short-term**

The effect of Taylor-White tool steel in essence established the practicability of interchangeable parts. For the first time, steel parts could be hardened and then machined precisely, preventing the warping that had, for decades, delayed the realization of machine-made, precision interchangeable parts. For the first time, the reality of Womack's ". . . *inexpensive* interchangeable parts would be found in tools that could do this job at high volume with low or no set-up costs between pieces" could be realized.

In addition and in tandem with the new cutting tool experimentation, the additional research guided by Taylor, on optimum feed and cutting rates did two things: (1) it showed that calculations for particular machines were possible and desirable, and (2) it showed dramatically the effects of making and using such calculations. Hounshell comments, "In Chapter 2 [sic] the question was raised of whether in the 1870s and 1880s high-volume, economical production of accurate parts was technologically possible. By 1913, when Colvin wrote the series in the *American Machinist* and when Ford initiated line assembly techniques, the machine tool industry was capable - perhaps for the first time - of manufacturing machines that could turn out large amounts of consistently accurate work."<sup>49</sup>

In other words, the work of Taylor and White concerned with producing high-speed tool steel capable of machining hardened steel parts was critical to the production of interchangeable parts; it was the key which had been missing for some 200 years. And, further, interchangeable parts were key to the evolution of high-volume mass production.

### **The factories in which these technologies were used**

In this time frame, circa 1900, state-of-the-art factories were designed after what has come to be known as "mill factories", taking their design cues from both grain mills and, later, the textile mills of New England. These mills were universally long, narrow, and multistoried. Biggs explains this architecture<sup>50</sup>. The building was long because of the power-transmission technology of the day, known as line-shaft/belt-drive. Initially powered by waterwheels or windmills, a long shaft extended the length of each floor, usually along each long side, driving machines by means of leather belts and pulleys (See Devine for a clean look at the details of LS/BD transmission). Each floor was long because, with the technology of the day, it was extremely difficult to make the drive shaft "turn a corner". Later, the "prime movers" - water and wind power - gave way to first steam engines and finally to electric motors. The buildings were narrow because the only available, practical lighting was daylight; each machine needed to be located adjacent to a window for the machinist to be able to see his/her work well enough to do it right. This meant narrow buildings with many windows; it also meant multiple stories. Here, material technology (limited to lumber and/or stone) provided other constraints.

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<sup>49</sup> Hounshell, p. 232.

<sup>50</sup> Biggs, p. 19.

First, there was a limit on the number of stories one could build vertically, because of the strength/weight ratios of wood and stone; generally about five stories was the maximum for a mill factory because of the stressing for the floors required by the weight of the machinery. In addition, because there was a practical limit of how wide a "clear span" could be traversed by either material, windows had to be tall and narrow to let in the maximum amount of light. It was the only practical way to build factories large enough to accomplish the work needed. If a single building wouldn't house the required machinery and workers, you simply built multiple buildings. Biggs has an excellent drawing of such a factory complex on Page 25<sup>51</sup>; for a later example, see photographs of Ford's three-story Piquette Avenue plant which was built and occupied in 1904<sup>52,53</sup>. Other visuals may be had by using Google/Images with the term "mill factory." In addition, there are many local examples throughout all areas of the United States still extant. It's simply a matter of recognizing what one is looking at, for few are still in operation as manufacturing sites; the best locations are in the older sections of the "downtown" areas of smaller cities which have usually been "re-developed", with the old mill factories recycled into eateries, apartment buildings, or retail centers.

Ford's Piquette Avenue plant was mentioned in particular because it was in this plant that the genesis of the Model T, destined to be the tool with which high-volume mass production was crafted, began. From leased space on Mack Street, where Henry Ford started, the Piquette Avenue plant in 1904 was designed and built for automobile manufacture. As Hounshell aptly puts it, "Until about two years before the introduction of the Model T the factory of the Ford Motor Company resembled more closely a poorly equipped job shop than a well-planned manufacturing establishment . . . operated by hard-to-find skilled machinists."<sup>54</sup> As demand for the Model T grew after its introduction in 1908, the Piquette Avenue plant became more and more crowded, until an entirely new plant - Highland Park - was completed in 1910. Ford's Highland Park plant represents the transition between "mill factories" and "flat factories". While it is problematic to argue that this "flat factory" form was *necessary* for the evolution of high-volume mass production, it is easily argued that the transition from mill factory architecture to flat factories eased this evolution.

Two new major technologies available made Highland Park different from its beginning. The first was electrification and the second was reinforced concrete.

Electrification provided two major advances in industrial architecture. First, it allowed the line-shaft/belt-drive system to be powered by an electric motor or motors scattered throughout the system; this allowed safer power transmission by eliminating the steam engine and its attendant fire hazards and boilers from the factory<sup>55</sup>. In addition, with increasing familiarity with electric motors, the "single drive" system was soon separated into multiple, smaller groups; this provided two major advantages: [1] the smaller machine groupings were no longer restricted to a single, long drive shaft and could there be located in nonlinear spaces

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<sup>51</sup> Biggs, p. 25.

<sup>52</sup> e.g., Brooke, Lindsay. *Ford Model T: the car that put the world on wheels*. Minneapolis, MN: Motorbooks, 2008, p. 42 or go to an Internet search engine like Google. Going to Google/images/Piquette Avenue plant brings up multiple images.

<sup>53</sup> Bucci, p. 38.

<sup>54</sup> Hounshell, p. 220.

<sup>55</sup> Devine, p. 361.

and [2] if one part of the system failed, the entire factory no longer drew to a shuddering halt while the system was fixed - which is exactly what happened with a single power source and a single driven line shaft system. This so-called "electric group drive" allowed a much more flexible and adaptive placement of machinery on the factory floor<sup>56</sup>. The second major advantage of electrification was the installation of electric lighting, which made practical for the first time a both a fixed work schedule (i.e., one that did not vary with seasonal lighting) and shift work. Earlier, work hours were determined by hours of available daylight, since kerosene lamps or gaslights provided neither the volume nor quality of light to allow machinists to do precision work. In addition, prior forms of lighting had two major disadvantages because they depended on combustion of fuel - they were hot and, because they burned fuel, they depleted the oxygen in the work space, leaving those in the workspace both hot and panting<sup>57</sup>. True, during the late spring and summer, the days were longer and the windows could be opened (thus renewing the oxygen and venting out both the heat and carbon monoxide), but factories needed to work year-around. Electric lighting provided the answer.

Reinforced concrete was a new concept when the Highland Park plant was being designed. In a seemingly-Jungian synchronicity:

- Alfred Kahn had just finished building a new factory for Packard Motors,
- Ford admired the plant and hired Kahn as the plant architect for the Highland Park plant<sup>58</sup>, and
- Julius Kahn (Alfred's brother) was one of the foremost American authorities on reinforced concrete and held basic patents in the field<sup>59</sup>.

Using reinforced concrete construction in the Highland Park building allowed much larger "clear spans", i.e., floorspaces clear of supporting columns, than ever before<sup>60</sup>.

What these two technologies - electrification and reinforced concrete - did was to give Kahn and Ford's team of engineers a chance to begin what Biggs terms "rationalizing the factory"<sup>61</sup> - designing the production process first and then designing the factory to house these processes<sup>62</sup>. And this is exactly what happened. Hounshell picks up the story, "P. E. Martin and Charles Sorensen laid out careful plans for a smooth move into the new factory. Henry Ford simplified their plans in 1909, when he announced that the Ford Motor Company would henceforth make only the Model T. . . Ford's decision allowed Martin, Sorensen, Emde, and Bornholdt to initiate the design, construction or procurement of large numbers of special- or single-purpose machine tools. This is what the American system of manufacture was all about."<sup>63</sup>

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<sup>56</sup> Devine, p. 350.

<sup>57</sup> See, for instance, Nye, David E. *Electrifying America: social meanings of a new technology*. Cambridge, MA: The MIT Press, 1997, p. 17.

<sup>58</sup> Hounshell, p. 226.

<sup>59</sup> Bucci, Frederico. *Albert Kahn: architect of Ford*. New York, Princeton Architectural Press, 2002, p. 31.

<sup>60</sup> Bucci, p. 31.

<sup>61</sup> Biggs, p. 2

<sup>62</sup> Hounshell, p. 227.

<sup>63</sup> Bucci, p. 40.

### Using the new developments: Ford's fusion

Hounshell states, "In planning for the large-scale production of the Model N, Henry Ford caught for the first time that age-old New England contagion for interchangeability. . . 'One of Mr. Ford's strong points was interchangeability of parts,' Wollering said later. 'There can't be much hand work or fitting if you are going to accomplish great things.' . . . Henry Ford essentially gave Wollering and Flanders carte blanche to fulfill that which he had promised."<sup>64</sup>. Further, the flexibility of machine placement, the new lighting equipment, and the clear-span factory floor gave the plant layout specialists the freedom to plan for what is now called "constant-flow throughput", i.e., machine tools arranged in order of use in the production process, rather than by function (i.e., "all grinders in that corner there, all milling machines in Building Two, and drill presses in the center of Building Seven," etc.)<sup>65</sup> And the work-scheduling system changed as well, adapting to the new plant layout. Thanks to Taylor's pioneering work in 1900, by 1910, Ford's production people had valid and detailed worktime data on every process on every part used in the Model T. Therefore, they could plan the daily capacity of the plant, pulling machines offline while the others maintained their daily averages, thus preserving not only effectiveness but efficiency as well.<sup>66</sup>

The use of special- and single-use machines - machines that do only one job but do that job extremely efficiently - allowed the use of unskilled labor.<sup>67</sup> Instead of skilled machinists using general purpose machinery to turn out parts, the unskilled machine operator became a machine tender, placing materials into the machine and pressing a button, lever, or pedal to start the automated machinery cycling through its operation - unfinished material in, hit the button, finished material out, copy after copy after copy. "Excited by the rationality of absolute interchangeability of parts and painfully aware of the problems created by noninterchangeability in the troublesome assembly process, Ford's production engineers placed accuracy at the top of the list in fixture and machine tool design requirements."<sup>68</sup>

The results were astounding. Before the first Model T was produced, agents had orders for 15,000<sup>69</sup>. This was a major development because prior to the Model T, Ford's average production was about 1,700 automobiles per year between 1903 and 1906, with a peak year in 1907 of 2,798.<sup>70</sup> Figure Two shows Ford production from 1908 through 1912.

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<sup>64</sup> Hounshell, p. 221.

<sup>65</sup> Hounshell, p. 221.

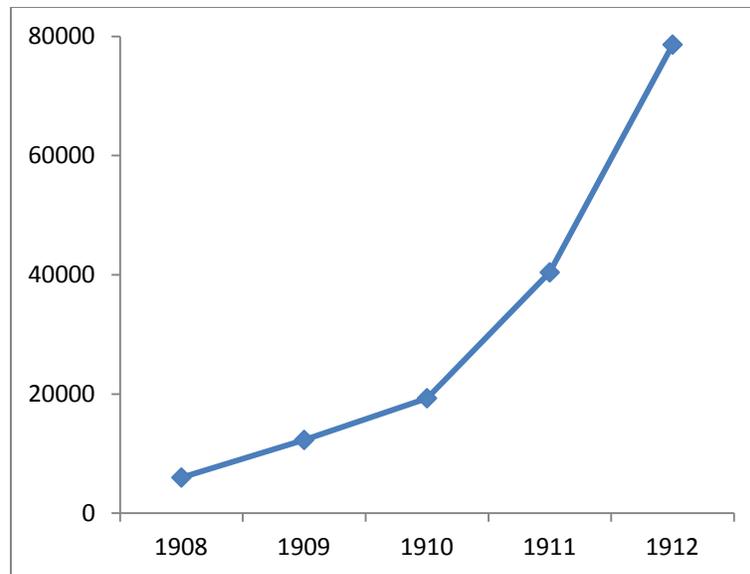
<sup>66</sup> Hounshell, p. 229.

<sup>67</sup> Hounshell, p. 250.

<sup>68</sup> Hounshell, p. 230.

<sup>69</sup> Hounshell, p. 219.

<sup>70</sup> Gunnell, John. *Standard Catalog of Ford, 1903-2003* (Third Edition). Iola, WI: Krause Publications, 2002, pps. 20-28.



**Figure Two: Ford Model T Production, 1908-1912.**

(Source: Gunnell, 2002, and Hounshell, 1985)

This shows a typical exponential growth curve; these curves in manufacturing are usually the result of experience as a team or company does a repetitive job over and over. However, this is not the case with this curve. This was anything but repetitive; it is the result of experimentation and process improvement<sup>71</sup> as the manufacturing process and the product - the Model T - changed. Ford and his production engineers were constantly experimenting, scrapping tooling, jigs and dies when a better (i.e., more productive) process was discovered.<sup>72</sup> In this time period, there was simply too much dynamic change in the Model T design and manufacturing process for a "learning curve" to kick in. This curve is a growth curve, but one due to evolution rather than experience.

There are several truly unique elements to this curve. First, production shows a growth of almost six times, i.e., >500%, in only four years; specifically, the number is 595%. This is phenomenal, especially in the days before mass communication and mass advertising. Secondly, and more germane to our case here, all of this took place before the very first assembly line was installed<sup>73</sup>. While there are disagreements about the location of Ford's first assembly line, there is no disagreement that it was installed on April 1, 1913. In the production figures related in Figure Two, there are no assembly lines included. The really, *really* big growth was yet to come. The growth shown in Figure Two was the result of a transition to better power distribution, better lighting and safety, better design, and the beginning of a transition to much more productive plant layout.

<sup>71</sup> Hounshell, p. 220.

<sup>72</sup> Hounshell, p. 234.

<sup>73</sup> The first assembly line was not installed until April 1, 1913; Hounshell, p. 247; Brooke, p. 62; Brinkley, p. 151. Of course other lines followed quickly, as the efficiency of the first was demonstrated!

## Summary and conclusions

Taylor is known primarily for his work with scientific management and what came to be called "efficiency engineering." I argue in this paper that his contributions to parts interchangeability are both more important and more lasting; the Taylor-White process for production of tool steel capable of machining hardened parts made interchangeable parts a reality - the end result of two centuries of hard work and experimentation.

Ford is known as the father of high-volume mass production, primarily for the moving assembly line. As in Taylor's case, I argue that Ford's most lasting and most important contribution is not the assembly line, but the *assembly system*, consisting of the creative and innovative search for solutions, of which the moving assembly line is only a single part. The fact is that a growth rate of 595% in four years, before the first assembly line was even attempted, shows that the assembly line itself is only part of a much larger system. I argue that it is the system itself that was and is Ford's greatest accomplishment.

History of Technology scholars often question the effect of "Taylorism" on "Fordism".<sup>74,75</sup> Essentially, such arguments are trivial because they miss the point. Taylor assumed the job, for example, was coal shoveling; taking this as a given, Taylor worked on improving the efficiency of the given job. This is a classic case of single-loop learning. Single-loop learning ". . . is sufficient where error correction can proceed by changing organizational strategies and assumptions within a constant framework of values and norms for performance.", i.e., works on the processes without examining or changing the goals/outputs of the processes.<sup>76</sup> Expressed differently, single-loop learning work on efficiency of process, assuming the goals of the process are valid. In essence, Taylor took the system or overall goals for granted and operated on the coal-shoveling process. On the other hand, Ford took nothing for granted except the goals of automobile production, questioning every part of the process/system. This is double-loop learning; "It is through double-loop learning alone that individuals or organizations can address the desirability of the values and norms that govern their theories-in-use."<sup>77</sup> Double-loop learning, in other words, looks at the effectiveness, asking if the goals of the system are valid. If they're valid, then it is time to look at process efficiency. In this case, Ford found the goals of craft manufacturing wanting. As Hounshell states, "The Taylor approach was to assume that the job of loading pig iron was a given; the task of scientific management was to improve the efficiency of the pig iron carrier . . . The Ford approach was to eliminate labor by machinery, not, as the Taylorites customarily did, to take a given production process and improve the efficiency of the workers . . . Taylor took production hardware as a given and sought revisions in labor processes and the organization of work; Ford engineers mechanized work processes and found workers to feed and tend their machines."<sup>78</sup> Therefore, discussions of who did what to whom in this context are moot; Taylor and Ford were doing two

<sup>74</sup> Hounshell, p. 249-251.

<sup>75</sup> Brinckley, p. 139-140.

<sup>76</sup> Argyris, Chris, and Donald A Schön. *Organizational Learning II: theory, methods, and practice*. Reading, MA: Addison-Wesley Publishing Company, 1996, p. 22.

<sup>77</sup> Argyris, p. 22.

<sup>78</sup> Hounshell, p. 252.

different things in two different contexts. Of course, their ideas had applications to one another, but a direct comparison is impossible, for it is comparing the proverbial apples to oranges. It is in this context that I argue that Taylor and Ford were joined, not as practitioner (Ford) versus theoretician (Taylor), but as two practical engineers working on successive problems, Taylor on interchangeable parts and process control, and Ford on the use of interchangeable parts on high-volume mass production.

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