Myth vs. Reality: The Question of Mass Production in WWII

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Abstract: The wealth of material published since World War II presents a picture burnished with technological gloss, total economic mobilization, and worldwide mass production. The truth is that, except for the United States, almost all production was "craft" production, i.e., traditional production characterized by labor-intensive, very expensive, low volume output. All nations utilized some aspects of mass production, and showed productivity far in excess of peacetime production, but only the United States had a true, mature mass production economy.

Introduction

Both the popular and technical literature of World War II presents a picture of all major combatants utilizing mass production to fuel their military efforts. The perception of the Allies was that all of the Axis powers, especially Germany, had rationalized and geared their economies for "total war", i.e., an all-out, 100% effort. In effect, the Allied war effort was largely directed by this perception - that the Axis partners had fully harnessed their economies to their war effort and only a similar effort on the part of the Allies could meet their advances. In large part, this was due to the tardy rearmament of the U. S. (started in 1939) and the United Kingdom (starting in 1936); as late as 1939, the U. S. Army was rated eighteenth worldwide, reinforcing this perception (Overy, 1995, p. 190).

I argue in this paper that this perception was largely incorrect. While the advances in peacetime by the Axis partners (Germany, Italy and Japan) were indeed impressive, they could not be sustained throughout the war, for reasons explained later in this paper. In all nations except the U. S., wartime production - both military and civilian - was largely “craft” production. Only in the U. S. was there true, mature mass production, as led by the automotive industry and pioneered by Ford (in production technique) and Sloan (in organizational structure) (Womack et. al.,

1990, pp. 40-41). These two innovations gave the U. S. the ability to [1] out-produce the rest of the world combined and [2] convert from civilian production to military production far faster than any of its partners or enemies.

This argument casts the analysis of both Allied and Axis effort throughout World War II in an entirely different light. It casts contemporary arguments about just-in-time and lean production technologies, likewise, in an entirely different light. It does indeed appear that the nation who takes these new technologies to maturity first will have an enormous competitive advantage, whether in the military sphere or in a civilian economy.

Prior to discussing the data, several distinctions must be made between choices in production technology. "Craft production" is distinguished by

1. producing output largely one at a time or in small batches,
2. high quality,
3. involving much handwork,
4. custom fitting of parts,
5. high costs (because of the highly skilled, labor-intensive nature of the work),
6. use of general-purpose tools, jigs and fixtures, and
7. low volume.

(See, for example, Womack et. al., 1990, pp. 88-91)

"Mass production" on the other hand is characterized by

1. little handwork,
2. interchangeable parts,
3. specialized tools,
4. automation,
5. unskilled or semiskilled labor,
6. moderate quality,
7. low cost,
8. moving final assembly lines, and
9. high volume. (Womack et. al., 1990, pp. 26-27)

Craft production was the norm for thousands of years; mass production was a product of the twentieth century, specifically pioneered by Henry Ford and his Model T between 1915 and 1920. By 1926, his company achieved a very large market share. However, Alfred Sloan of General Motors, in trying to compete with Ford's production technology, saw that the major weakness of Ford's approach was Henry Ford himself. Ford had made himself vulnerable to modern organizational, financial and managerial advances as a "one man show" who had a passionate distrust of banks; for example, financing most early advances was done from cash held in the safe at Ford's headquarters. Womack et. al. (1990) state, "He financed all his projects internally, for Ford loathed banks and outside investors and was determined to maintain total control of his company . . . Ford had absolutely no idea how to organize a global business except by centralizing all decision-making in one person at the top - himself." (p. 39) Sloan led GM to the organizational structure improvements that brought GM into competitive distance of Ford, primarily in management, organizational structure (pioneering the divisional structure), and marketing (Womack et. al, 1990, p. 42)

Another peripheral matter must be discussed, relative to the theme of this paper; this is the matter of "rearmament speed". In 1939, the U. S. Army had " . . . an air force of 1,700 largely obsolescent aircraft and a mere twenty thousand men." (Overy, 1995, p. 190) The Japanese has begun serious rearmament in 1931, with

her incursions into Manchuria and China (Hoyt, 2001, p. 81). Germany began an increased armaments program in 1935 (Budiansky, 2004, p. 190), with the British following suit in 1936 (Budiansky, 2004, p. 195). In Morison's words, "If England slept, America not only slept but snored." (1963, p. 6) In other words, the rearmament of the United States took less than a year, while that of the other major participants took four years or more. In Overy's words, ". . .how did the United States turn itself in a year into a military super-power, when every other state had taken years to rearm?" And, germane to this argument, " . . . why did Germany, with so rich and industrially developed a continent at her disposal, produce so much less than the Allies?" (1995, p. 51)

The Numbers

The primary data used to support this argument is taken from aircraft production figures from all participants. This is not because this is an isolated industry or case, but because aircraft were the most complex systems in widespread demand at the time. But the same arguments may be made and supported for everything from vehicle production (trucks and tanks, for example) to ships (Liberty ships and U-boats as examples). However, the aircraft industry was chosen because the data on production are widely available, aircraft represented the most technologically advanced weapons systems used in World War Two, and because aircraft were in such high demand on all fronts, requiring mass production. In addition, early experience in World War Two proved conclusively that military or naval operations could not effectively take place in the absence of air superiority. The aircraft was therefore not only pivotal, but also representative of the characteristics we seek to study, i.e., the unstructured questions (at the time), "Are complex, advanced weapons amenable to true mass production, or must they be made with craft practices? Which is more important - quality or quantity? What about keeping them up-to-date? Can modifications and improvements be incorporated without disrupting the assembly line or are they so complex that they may be only hand-built?" For these reasons, and because all of these questions were indeed answered during the war years, the aviation industry was chosen for the data to present this argument.

There are two things to immediately note about these figures. First, no two sources in either the primary or secondary literature agree exactly (or, in some cases, even come close to one another). This is because of differences in accounting and counting practices, destruction of records at the end of the war, and simply transcription error over the years. Second, by careful comparison of multiple reliable sources from multiple countries, a rough approximation may be made. These sources are from Overy (2005) and represent, I believe, reliable numbers for examination and analysis.

Graphs One, Two, and Three show, respectively, aggregate aircraft production, aircraft engine production, and airframe weights. Further evidence is presented in Tables One, Two and Three. Simple linear regressions were run for each data set by country, with year as the independent variable and production volume as the dependent variable. The 1945 data were excluded because, by that time, each participant was either defeated or running down production prior to converting back to civilian goods.

Making the Case

As late as 1939, the aviation industry worldwide was tiny; aircraft (both civilian and military) were essentially handbuilt to tiny contracts; for example, in 1939 the entire U. S. military aviation establishment consisted of only 500 combat-worthy aircraft (Brinkley, 2003, p. 452). In 1941, after two years of war, the British produced only 498 bombers during the entire year (Overy, 1995, p. 109). The same was true for aviation components - the engines, propellers, landing gear, and so on. There was no experience anywhere at aviation mass production, because the question had never arisen.

In addition to this problem was the question of system complexity. For example, a B-24 Liberator bomber (an American four-engined heavy bomber), took 550,000 parts, not including the 700,000 rivets (Brinkley, 2003, p. 465; Budiansky, 2004, p. 254). According to Perret, "the B-25 medium bomber, half the size of a B-24, contained 165,000 separate items not counting the 150,000 rivets that held it together," (1993, p. 39). In comparison, the average automobile of the time contained about 15,000 parts (Brinkley, 2003, p. 458.) Mass production had never been attempted on anything even approaching this level of complexity.

Despite the vicissitudes of the Great Depression (1929-1939), by the late 1930s, true mass production, combining the industrial techniques pioneered by Ford and the organizational advances introduced and sophisticated by Sloan at GM, was accomplished in the United States (Womack et. al, 1990, pp. 40-42). Oddly enough, in this time period, Ford had shared his production techniques to anyone interested throughout the world. (Womack et. al, 1990, p. 45)

However, the diffusion of these techniques was very slow outside of the U. S. The craft tradition of the European labor force and the highly-restricted and -segregated class structure of the managers made adoption of these techniques proceed at a glacial pace. As Womack et. al. (1990) state,

> "The basic ideas underlying mass production had, therefore, been freely available in Europe for years before the onset of World War II. However, the economic chaos and narrow nationalism existing there during the 1920s and early 1930s, along with a strong attachment to the craft-production traditions, prevented them from spreading very far." (p.45)

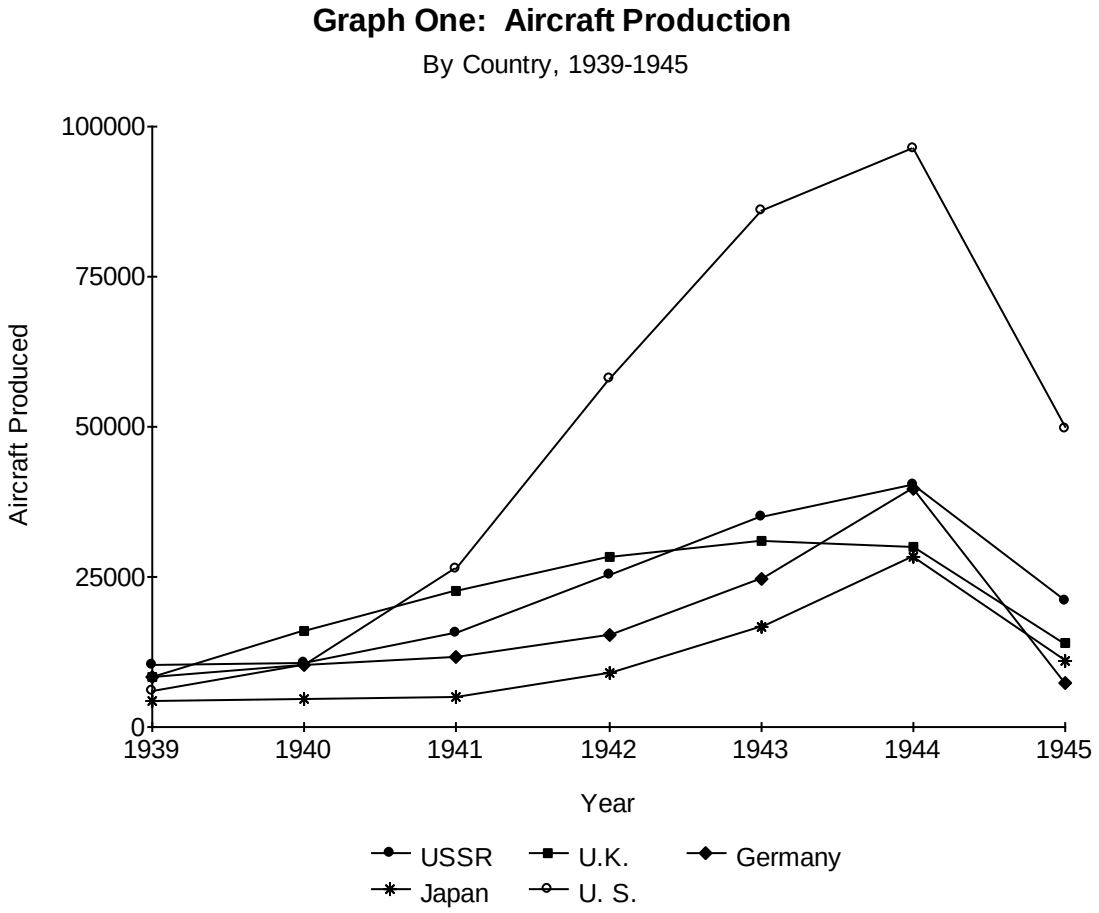

Table One: Pertinent Aircraft Production Regression Data By Country (1939-1944)

	Slope	r^2	Sy.x	t*
U. S.	19804	0.97	9562	-8.17
U. K.	4692	0.96	3021	-5.73
USSR	6637	0.97	3259	-7.80
Germany	5863	0.91	5502	-4.11
Japan	4518	0.89	4763	-3.72

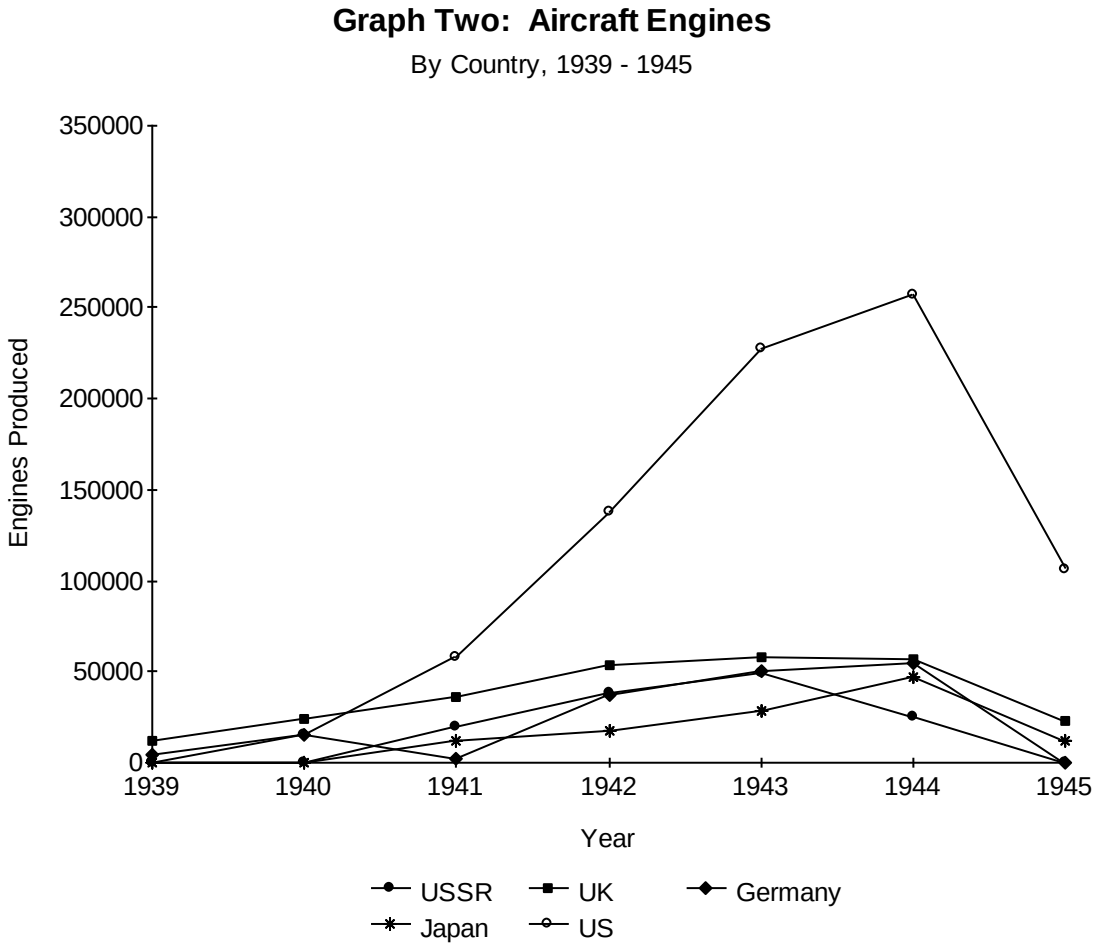

Table Two: Pertinent Engine Production Regression Data By Country (1939-1944)

	Slope	r^2	Sy.x	t*
U. S.	57108	0.98	24957	-9.10
U. K.	9750	0.96	6350	-5.78
USSR	12120	0.97	6210	-7.73
Germany	10681	0.99	2918	-14.24
Japan	9217	0.96	5374	-6.84

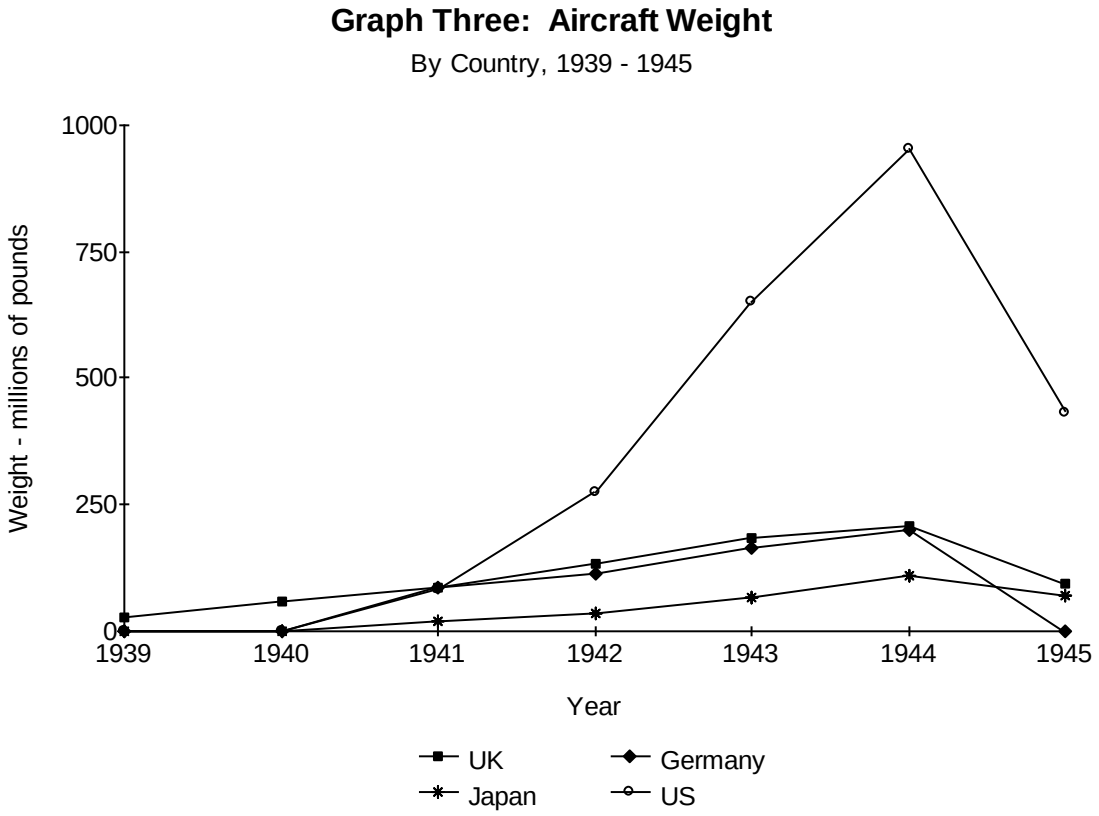

Table Three: Pertinent Production (by Weight) Regression Data By Country (1939-1944)

	Slope	r^2	Sy.x	t*
U. S.	197	0.94	151.0	-5.44
U.K.	38	0.99	8.8	-16.55
Germany	43	0.98	18.0	-9.46
Japan	22	0.95	14.75	-5.87
USSR	data not	available		

This left all World War Two participants, except the U. S., using craft production; the only alternative was reliance on immature, incomplete mass production systems. Throughout Europe (including the U. K.), Overy (2005), says,

> " Aircraft production in the early 1930s did not lend itself easily to such methods. Production was usually carried out in workshop batches with workers moving from aircraft to aircraft, carrying out tasks in an unscheduled way on one or two aircraft at a time, using a large degree of handwork. Tools were of a general-purpose kind so that the largest number of operations could be

> performed by skilled men working in groups on each aircraft. During the war the best practice at the largest American plants resembled that of the major car firms. Flow production methods were introduced, long and narrow factory halls build for moving aircraft from stage to stage of its assembly, while conveyor belts fed parts into the main line at appropriate points. Workers were scheduled carefully to perform particular tasks at particular sites along the assembly line, while general-purpose tools were replaced by special machinery designed for a higher level of automation. A high degree of standardization and interchangeability was introduced and handwork reduced to a minimum." (p.169)

In contrasting U. S., U. K., German and Japanese production, he states,

> " . . . the Ford Plant at Willow Run, despite opposition to the scheme from the air authorities, undertook to mass-produce the B-24 bomber, and by breaking production down into 20,000 separate operations it was finally achieved in 1944.
>
> "British factory practice was still far below that of the most efficient American firms . . .
>
> "In Germany, the aircraft factories were slow to adopt new methods and were permeated by many built-in inefficiencies which it proved hard to overcome. One of the hardest was the degree of handwork involved in producing aircraft. Handworker methods survived through the legacy of the early industry in the 1930s and because of the high degree of skill acquired by the individual *Meister* (the master-craftsmen) (italics in the original) through a long and rigorous apprenticeship. The workforce resisted attempts to undermine the skills or to dilute the workforce by using new methods and semi-skilled labour. Batch production gave way only slowly to line production, while time-and-motion studies on which American practice rested were either not introduced or where they were, proved unworkable because of the traditional methods of work payment and use of skills. Conveyor belt production and rational factory organization developed only slowly and major factories still had little evidence of modern methods even by 1945.
>
> "Japanese factory methods were even more primitive . . . the problem was the consequence partly of competition between the army and navy who could not even agree on a common voltage for electrical components until late in the war. But as in Germany a major barrier to greater efficiency was the problem of organizing and scheduling the flow of production." (p. 170)

Photographs from the era show this difference. Classic photos from Vickers and DeHavilland (British) and Junkers and Heinkel (German) production facilities show isolated aircraft in "final assembly", in stationary jigs, being assembled by "work gangs", embodying the "craft production" process. In contrast, photographs from Grumman, North American, Republic, and others show "rolling final assembly" processes, with aircraft moving from station to station, much like Model T assembly twenty years earlier. [See, for example,

Price (1974), Wrynn, (1995), and Dressel and Griehl (1993)]. Overy (2005) comments further:

> "The fact that emerged most clearly from the experience of labour mobilization was that unskilled labour, provided it was adequately trained and provided that more mechanized and routine production methods could be introduced, was more productive than labour in the pre-war aircraft industry with its high reliance on skilled workers. In the United States the dilution of the workforce was readily accepted because of the use made of new factory methods.
>
> "Airframe weight per employee/month increased from 21 pounds in January 1941 to a peak of 96 pounds in May 1944. Aircraft production itself was broken down into a long series of easily learnt processes which required the minimum of manual skill. In Britain and Germany, however, the habit of using highly skilled workers was hard to lose.
>
> "In Germany the task of dilution was more complicated. First of all the *Meister* resisted the reduction in training time and the changes in apprenticeship regulations necessitated by wartime conditions. Second, the aircraft firms had always relied heavily for production on a high degree of skilled work, and the factory methods had been introduced in the expectation that such methods, and the high quality of finish required for aircraft, would be maintained under war conditions . . . For the first two or three years of war the skilled labour shortage was combated by every means possible in defence of the high standards of workmanship traditionally associated with German engineering . . . The price paid for a very high standard of finish was a smaller number of aircraft completed." (p. 173-174)

Magenheimer puts this problem even more succinctly, when he says,

> "The lead in productivity that the United States and Great Britain enjoyed over Germany gave the Western Allies an advantage that could not be overcome. What proved to be decisive were their advances in standardizing production methods and their higher per capita productivity. The Germans, who concentrated more on technological flexibility and qualitative superiority, were left behind in mass production . " (1997, p. 184)

Discussion

A cursory glance at these graphs will show the great disparity between U. S. production and all of the other participants; the differences are not of percentages, but often orders of magnitude. The regression data show the same startling differences. The slopes for U. S. figures in each table are much steeper than the other participants. The t* figures shows that, in each case, the slope is real as opposed to being a statistical artifact. By the same token and within rough limits, the slopes, coefficients of determination, and the standard errors show the U. K., the USSR, Germany and Japan all producing at similar levels. However, for example, in Table One the slope for U. S. production shows a large and real difference compared to the other participants, 2.98 times (or 298%) the nearest country.

While there are obviously resources differences between countries, this cannot be the primary explanation for such productivity differences. For example, Germany had all the resources - natural and human - of Western Europe from which to draw; granted, these resources were not willingly and enthusiastically provided but were taken by force. Even so, they were still available. In addition, in 1939, surprisingly enough, Germany was the world's largest producer of aluminum, a key resource in aircraft production. (Overy, 2005, p. 176) The United Kingdom had the resources of a world-wide empire from which to draw, although this vastly complicated logistical considerations. The USSR, too, had vast Siberian resources from which to draw, although the rudimentary transportation system interfered with rational utilization of these resources. In fact, only the Japanese were truly "resource bound", which is the primary reason they went to war, annexing the resource-rich areas of southeast Asia.

Neither can human resource limitations, technical skills, nor industrial ingenuity explain away these differences; each of the major participants had been major worldwide industrial powers since World War I ended in 1918. While it is true that the USSR and Japan had been later in modernization than the other participants, even both of these late entrants had strong and well-established light- and heavy-industrial communities, backed by strong academic, engineering, and technical traditions.

If the differences in productive output, and the vast difference in rearmament speed, cannot be explained by resource limitations, human resources, or technical and industrial constraints, wherein, then, lies the explanation?

Emergence

"Emergence" is a concept that comes to us from the rapidly-developing field known as "Complexity Theory." Emergence is that property of a system that comes from the interaction of its parts. It cannot be found nor analyzed by study of its component parts, but comes from the system as a whole. Of course, the most obvious and widely-used example of emergence is life itself; we cannot combine the chemicals which comprise the human body and get life. Life emerges from the interaction of the chemicals themselves and a vast array of developmental processes. As Gharajedaghi (1999, p. 45) puts it, "Emergent, or Type II, properties are the property of the whole, not the property of the parts, and cannot be deduced from properties of the parts. However, they are a product of the interactions, not a sum of the actions of the parts, and therefore have to be understood on their own terms." Consider then the following, and think about their interactions:

- In 1908, Ford brought out the first Model T, with the avowed purpose of "putting America on wheels, with an automobile in every garage".
- By 1926, the Model T's peak sales year, Ford led the entire worldwide automotive industry in terms of market share, indicating that all major problems with the mass production techniques pioneered by Ford had been worked out.
- By 1932, even as the Great Depression deepened, Chevrolet sales had eclipsed those of Ford, indicating that the confluence of Sloan's organizational structure changes and Ford's production techniques were successful.

(Winnewisser, 2005, p. 195-196)

- In 1937, per 1,000 inhabitants, the U. S. had more than 200 cars and trucks, Germany, 16 and Japan, less than one. (Overy 1995, p. 224)
- In 1938, with unemployment at 19%, Detroit produced and sold just over 2,000,000 new automobiles (Consumer's Guide Editors, 2004, p. 315). In the same year, Toyota produced 458 automobiles, Honda, 1,242, and Datsun, 2,908 (Overy, 1995, p. 221). According to Brinkley (2003, p. 370), in 1926, world-wide ratios of people per vehicle were:

Australia	30
China	31,871
Japan	1,789
Britain	49
France	54
Germany	194
Italy	353
United States	6

- In 1941, Detroit produced more than 3.5 million automobiles (Overy, 1995, 193), this at a time when the U. S. was still recovering from the Great Depression and unemployment still stood at 17.2% (Consumer's Guide Editors, 2004, p. 348).
- All Fords of the time (i.e., Model Ts, Model As, and Model Bs and "8s" of 1932) were specifically designed to be repaired and maintained by their owners and were provided (as standard equipment) with tool kits and repair/maintenance instruction manuals (Womack et al, 1990, p. 30). They state,

> "To appeal to his target market of average consumers, Ford had also designed unprecedented ease of operation and maintainability into his car. He assumed that his buyer would be a farmer with a modest tool kit and the kinds of mechanical skills needed for fixing farm machinery. So the Model T owners manual, which was written in question-and-answer form, explained in sixty-four pages how owners could use simple tools to solve any of the 140 problems likely to crop up with the car. For example, owners could remove cylinder-head carbon, which causes knocking and power loss, from chamber roofs and piston crowns by loosening the fifteen cap screws that held the cylinder head and using a putty knife as a scraper. Similarly, a single paragraph and one diagram told customers how to remove carbon deposits from their car's valves with the Ford Valve Grinding Tool, which came with the auto."

Therefore, since 1908, the automobile industry had been inadvertently training a large American population of mechanics; this trend was accelerated by the requirements of the Great Depression, where money for automobile repairs was severely limited. Countries without this great scale of mechanization lacked this training, however informal. In other words, the automobile industry, coupled with the Great Depression, "grew" an entire generation of mechanics and engineers.

- Further, Bergerud (2000) states,

> "For the Allied air forces it was a priceless advantage that Western economies were firmly in the era

> of the internal-combustion engine. Furthermore, because times were hard, anyone with any technical aptitude maintained their own cars, trucks, and tractors to save money . . . Put simply, the Allied nations were relatively rich, almost completely literate, and brimming with healthy young people who knew how to use a monkey wrench." (p. 17)

He further states,

> "In great contrast to the United States and the other Allies, much of Japan's economy remained in an agrarian age. The young men who could fix an ill-behaved Model T or tractor were few in comparison. As to high school and higher education, at least as America knew them, they were much more developed in the United States than in Japan. It was a bad omen when on March 23, 1939, the original Zero prototype [Japan's premier fighter aircraft - JP] was disassembled, loaded onto oxcarts, and moved over poor roads to the large naval air base at Kagamigahara prior to its initial flight. Young Japanese of the era were tough, tenacious and all too used to discipline. They were not, however, handy with the all-important monkey wrench." (pp. 320-321).

Further,

> " . . . the pool of well-educated and extremely healthy young men was far smaller . . . These young men were fifteen to seventeen years old and initially were required to be primary school graduates; in 1937, the standard was raised to middle school." (pp. 322-323)

- World War II was, from the start a mechanized war; as Overy (1995, p. 210) states, "The core armoury of offensive warfare in the Second World War consisted of aircraft, tanks, and trucks."
- One of the primary requirements for true, mature mass production is parts standardization leading to truly interchangeable parts. This required design simplification for manufacturability, which in turn required both specialized machinery/automation and job simplification. Job simplification, in turn, led to the use of unskilled/semiskilled labor to reduce costs. This system, matured and streamlined, was already in place in the U. S. by the mid-1930s.

Any of these data, taken separately, would not be important. However, taken in the aggregate and ***relative to the "emergence argument"***, they show [1] the enormous impact of mass production on WWII, from actual production to artifacts such as the training of military recruits already accustomed to working on machinery, [2] that the U. S. had an enormous lead in mass production and organization, [3] that, because of this lead started in the 1920s and matured in the 1930s, the conversion of mass production facilities from civilian production to military production was accomplished rapidly - at least "rapidly" relative to the conversion of the other participants, and [4] that, once

accomplished, this conversion was extremely effective and productive, as is shown in Graphs One, Two, and Three.

Summary and Conclusions

This paper has argued that, of all the major participants in World War II, only the U. S. had a mature mass production system in place. The other participants were caught up in the conversion from craft production to mass production; while their individual productivities did increase during the war years, it strained their craft economies to the utmost; this also increased their conversion times (i.e., converting from civilian to military production), further straining the economies, tempers, and motivations of all involved. By contrast, the conversion of the U. S. economy went very rapidly (although not without a great deal of strain) and became productive far sooner than anyone - Allied or Axis - predicted. The stage for this conversion was set far earlier, with Ford's invention and sophistication of industrial techniques and GM's invention and sophistication of an organizational structure capable of professional management, finance and marketing of such a productive system. These two, in confluence, produced a true, mature mass production economy by the mid 1930s that truly became Roosevelt's "Arsenal of Democracy", when turned to military production.

This study would be of only slight historical interest but for a single point. With the advent first of Just-In-Time technology, brought together as a system first by Toyota and then later adopted much more widely, and the more recent discussions of "lean production" throughout industry and detailed by Womack et. al., this topic goes far beyond mere historical interest. Thankfully lacking the military imperative of a conflict like WWII, nonetheless the competitive advantages of taking such a technology to maturity from the leading edge are obvious. Just as the U. S. took advantage of Confederate General Nathan Bedford Forrest's dictum of "getting there first with the most", whoever masters JIT, lean production (JIT's heir apparent) and future advances will have a very large competitive advantage indeed.

As our environment continues to change at an ever-increasingly rapid pace, the ability to adapt, learn, and apply will become more and more important. As the U. S. auto industry, especially Chrysler (now Daimler-Chrysler) and General Motors, have learned, ignoring new technology and processes comes at an accelerating price. This is the same lesson that the Axis powers learned during World War II.

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