Producing a Machine Tool Revolution

By Stuart Rosenblatt

June 19, 2018—The following is part two of a series dedicated to "Lessons for a Recovery: The WWII Economic Mobilization." Part one appeared on May 18, and can be found [here](#) .

The summer of 1940 witnessed a dramatic escalation of the U.S. war effort, thanks to the fact that Hitler had carried out his successful blitzkriegs against Belgium, Luxembourg, the Netherlands, and France. On May 16, President Roosevelt had called for emergency appropriations for a military buildup, including the demand for production of 50,000 planes a year. By June 25, Congress had appropriated $4 billion, and authorized the Reconstruction Finance Corporation (RFC) to purchase, lease, and build production plants, as well to (in Jesse Jones' words) "do almost anything else that would strengthen the nation's armed might."

A lathe operator during the economic mobilization for World War II.

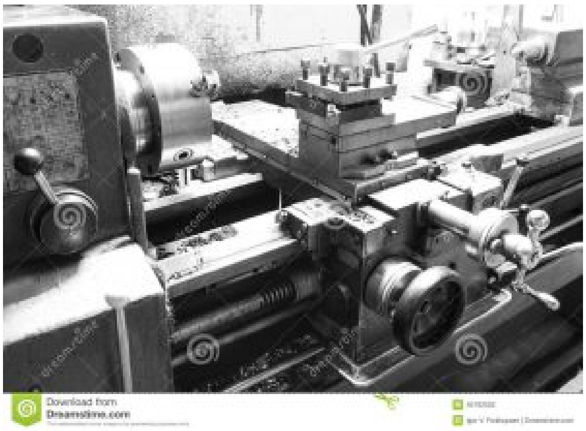
The RFC created four corporations to aid in carrying out its mandate: the Rubber Reserve Company, the Metals Reserve

Company, the Defense Supplies Corporation (DSC), and the Defense Plant Corporation. To coordinate between the RFC, these new corporations, and the government institutions responsible for the war, FDR then established the National Defense Advisory Council (NDAC). Jesse Jones, although not on this board, remained the President’s pointman. In fact, his responsibilities expanded when FDR appointed him Commerce Secretary on top of his other jobs.

An Extraordinary Demand

The nation was faced with the need for a dramatic increase in production, intake, and storage of necessary equipment and supplies. All areas of physical output had to escalate simultaneously. Because the United States had dismantled its WWI industries, and was still emerging from the Depression, new facilities had to be erected. Production demands for all weaponry began to accumulate at a rapid pace, especially to supply those resisting Hitler in Europe, mostly the British.

Each service calculated the type of equipment it needed and placed orders with the government, especially the NDAC. The NDAC then collaborated with the RFC and others in the private sector to fulfill the orders. This process did not work smoothly throughout the entire war, and was subject to constant intervention by the President. The first step was to chart out the bill of materials for each area. The minute production began, shortages, and bottlenecks appeared on everything from raw materials to steel, manganese, aluminum, etc. But we begin with the most critical item: machine tools.



A caliper lathe machine tool from the WWII era.

Machine tools were the most crucial marker for the entire war effort. No machinery could be built, let alone mass produced, without the requisite machine tools. Machine tools are the machines needed to build other machines. They included: lathes, milling machines, automatic screw machines, precision grinders, iron planers, and other types of metalworking machines. The metal working machines had several major characteristics of action: milling, drilling, turning, grinding, shearing, pressing, planning, and broaching.

According to Gordon Wright, as historian Francis Walton put it, "Toolmakers are the master builders of the machine age.' They could transform a 200 pound lump of metal into a 75 pound propeller shaft, precisely turned, rounded and gleaming. The shaft was but one of 17,000 parts of an air-cooled aircraft engine, and relatively simple one at that. Forming the cylinder barrels alone in 1940 required no less than eighty-eight separate machine tools." (Arms, p. 64)

Airplane manufacturers designed the engines, fuselages, wings, and other parts they needed; sent the blueprints to the machine tool manufacturer; and the toolmaker then figured out the process. He told the company what tools they would need and in what order on the assembly line they would be used; then they built the machinery.

The configuration of machinery required was predetermined by the strategic contours of the war, which was being waged differently than previous wars. For example, air war, which played an inconsequential role in the previous conflict, emerged quickly as a crucial component of this war. Thus, new types of machinery would be required to construct the new weapons of combat.

Machine tools, as has been discussed by Richard Freeman and others, express the unique convergence of human ingenuity, creativity, and physical proof of principle. On the one hand, they require cognitive breakthroughs in conceiving the new idea, which appears initially as a vague, but profound insight. That insight then must be transformed into a rough working model, and eventually into a new tool, whose implementation transforms and upgrades the productive process.   A successful result will produce a dramatic increase in productivity, but will be qualitative. As an example, observe the difference between the biplanes of WWI and the B-29 Super-fortress of WWII.

The B-29 of World War II.

World War I biplane.

Ironically, development of new machine tools cannot be done assembly-line fashion; they demand highly skilled workers to build the new tools, one item at a time. Then the new machines can be configured to realize the required improvement in output. Many machine tools can be placed in an assembly line to ensure rapid completion in factories that have to be built to accommodate this approach. The machine tool configuration has to be conceptualized, designed, tested, and produced on schedule to ensure that the newly constructed factory would not sit idle, since production could not begin without everything being in place.

Thus machine tool production was the top priority.

As the demands of the war changed, new technologies would have to be designed to replace old ones, even those that had just been developed. For example, new tanks which were produced in the beginning of the war with riveting, were shown to be inadequate to withstand the German ordnance. They were replaced by large metal plates, which proved far more resistant to attack, and even that was soon discarded. Similarly, rotating turrets replaced the fixed housing at the top of tanks, allowing them to actually aim and fire at nearby targets. Whole new technologies were designed, new machine tools created, and the process was upgraded.

Similarly, when newer methods of utilizing electricity in production, including plane and ship construction, were developed, plant designs had to be altered, and machine tool demands changed as well.

The result was an enormous upgrade in productivity, output, and what economists call Total Factor Productivity, the impact of these new technologies on output.

The “Keystone of the Industrial Effort”

An overview of the progress of the machine tool industry throughout the war underscores its central role and importance. As Donald Nelson, who ultimately headed the War Production Board (1942-44), wrote in *Arsenal of Democracy*, “Long before the war, the Army and Navy Departments realized that machine tools would be the keystone of the industrial effort during the war…

“By April 30, 1941, President Roosevelt had become aroused over the machine tool shortage. He wrote to Bill Knudsen and Sidney Hillman urging the necessity of speeding up the manufacture of machine tools. A seven-day week and twenty four hour -day schedule was recommended by the President, but although the machine tool bottleneck showed some improvement, it always remained narrow. This equipment was necessary to gear the whole production process, but the craftsmanship needed to build was a scarce article, and there were not many areas in the whole country where such craftsmen could be found. The United States undoubtedly had more machine tools than any other nation, but no shortage confounded our defense production as much as this one.” (as quoted in Freeman, “America’s Machine Tool Design Sector has Shrunk,” February 7, 1997, *EIR*)

Donald Nelson, right, head of War Production Board, with vice-president Henry Wallace.

At the high point of WWI, United States' machine tool production had increased from 40,000 units per year at the war's outset, to 150,000 by 1919. During the Depression, however, it fell off drastically reaching a low point of 10,000 units per year from 1931-34. It increased during the New Deal industrial and infrastructure development policies to 34,000 per year in 1938. But with a gigantic increase in demand and modernization, machine tool production increased tenfold by 1942. The United States was turning out over 300,000 tools per year between 1938 and 1942.

In 1939, U.S. machine tool industry expansion was driven by orders from Great Britain, France, and even Russia. In that year, half the U.S. tool output went overseas; in 1940 it was 75%. The demand forced the industry to modernize, and quickly. In 1939, experts considered fifty percent of United States' machine tools to be obsolete and in immediate need of replacement. A survey in that year concluded that 85% of the machines were over 10 years old, and some of them had been built prior to the Civil War! (Finney, Arsenal of Democracy, p. 9) The shortage of toolmakers to build the new machines made things worse.

The demand for tools was immense. Two factories built by the government and run by Studebaker required 3500 machine tools each. A third required 13,000. The industry was concentrated in Michigan, Indiana, Ohio, Pennsylvania, and Massachusetts. Not accidentally, these were the centers of the auto industry, which was the largest consumer of the specialized instruments.

In an October 1942 article in *Automotive and Aviation Industries* magazine, George Johnson, president of the National Association of Machine Tool Builders, gave an example of how the new modern machine tools improved productivity: "One of the most difficult and important assignments given the machine tool industry was the design and building of hundreds of special-purpose machines, needed to convert the aircraft engine industry from small-lot to mass production… for example, specially designed machine drills, countersinks and spot-faces 22 identical three-eighth-inch holes in an aluminum airplane engine crankcase.   It works simultaneously on 32 holes from two different directions. These operations previously took two hours 12 minutes. This one new machine completes the job in 23 minutes." (Freeman, p. 53, Feb. 7, 1997, *EIR*)

This single improvement shortened the process to one sixth of the time, and is a prime example of increased productivity, driving the Total Factor Productivity.

Converting to Tank Production

The same process characterized all the new industries. Let's take the example of the conversion from automobile production to tank production. A process that originally appeared to be simple required nearly *200 pounds* of blueprints for the construction of the first prototype.

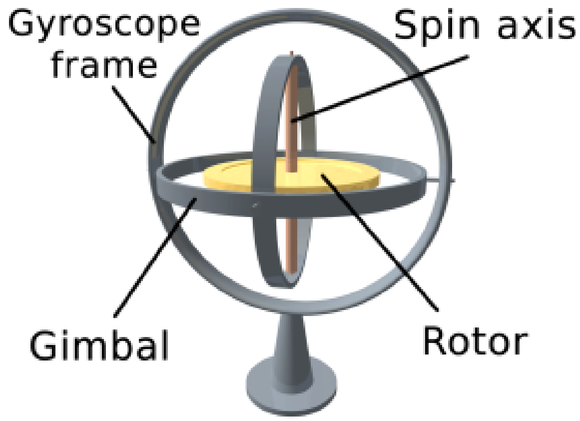
Tank production demanded a new type of assembly line, and new sets of machine tools had to be designed. This usually entailed building new factories. The first tank used as a model from which to extract specifications was rejected by the Army as already obsolete! The entire process had to be redesigned.

Riveters at Lockheed Martin.

Chrysler Corporation, an early leader in tank production, turned its operation over to Edward Hunt, who was considered a genius in machine tool construction. “He could read a blueprint like a conductor read a musical score, seeing not merely what was on it but what was in it. The tank had 3,500 parts, some simple and others requiring as many as fifteen operations. Some could be made on standard machines; for others special machines had to be designed and built. By calculating how many machines of what size were needed altogether, Hunt could figure the size of the building required to house them, along with the assembly lines, railroad track, receiving station, and other essentials. The building turned out to be a quarter mile long and a tenth of a mile wide.” (Arms, p. 253)

The new mockup that Hunt constructed placed all the machines in their proper order and coordinated this with the arrival and placement of thousands of parts. He had to get the right machines in the right place and in the exact order, so assembly could proceed on time. Even after this was done, the tanks went through numerous modifications as the exigencies of combat changed the necessary design and production. For example, it was determined early on that the tanks would be safer if the body were recast in a single mold rather than built up by sections of armored plate riveted together.

Then there was the matter of the stationary firing turret, which limited the tank's targeting ability. Westinghouse Corporation attacked this problem, and ultimately came up with the idea of using "gyroscopes and their little known property to respond instantly to changes in rotational speeds at right angles to their own axis." This permitted stabilization of the gun turret and allowed the tank to fire while moving in different directions. This technological breakthrough necessitated large numbers of wholly new machine tools to be produced, but it changed the face of U.S. warfare. As one U.S. General later quipped, "A tank that must come to a dead stop to fire accurately itself becomes an excellent target… Since American tanks can be always in motion, they make difficult targets."(Arms, pp. 255-56)



The principle of the gyroscope was key to solving the engineering problem in tank production.

This was a prime example of the key to machine tool production: A new idea, like that of a symphony or a poem, emerges in the mind of the inventor. It is then communicated in some inchoate form and finds its way into the design of a new machine, and then a new machine tool, or set of new tools. Once implemented, it increases the productive capability of the process.

From the beginning, the private sector was reluctant to dive into machine tool production on its own dime, despite the fact that orders from abroad were beginning to pile in during the summer of 1940. With the memories of post-WWI financial difficulties in mind, both large and small shops moved very slowly to fill the orders. Much of the capital committed during WWI had come from the producers themselves, and when the war ended, they were left high and dry, with empty plants and years of amortization ahead. So in 1940, the Defense Plant Corporation (DPC) jumped in to meet the requirements.

Building the Facilities

Under the sponsorship of the War Department, which made the formal requests for machine tool orders, the DPC financed the construction of 35 new machine tool plants, and it also paid for the machinery to fill 131 more factories. The Defense Plant Corporation ultimately spent nearly $2 billion on machine tools during the war. It supplied many of the machine tools for the airplane industry expansion; it spent $217 million on tools to make lenses for the optical industry; and $335 million for the transportation industry. Among its largest contributions were the tools to build the Big Inch and Little Inch oil pipelines that moved massive amounts of oil from East Texas to the East Coast. This relieved the burden put upon Atlantic Ocean oil tankers, who were under continuous attack from German submarines.

U.S. Army Detroit Arsenal Tank Plant.

The DPC underwrote 30% of the financing for the tool production, relieving wary producers of the danger of being “hung out to dry” if production, delivery, and payment ran afoul as it did after WWI.

Prior to Pearl Harbor, the government worked with private industry to invest in new plant and equipment. The private sector shouldered a significant part of the burden, but the government used tax amortization and accelerated depreciation schedules to ease the load. Due to infighting and residual fears of WWI profiteering, the amortization policy was mostly adopted by the Army and Navy Departments. Nevertheless, tax amortization covered nearly $6.5 billion in new plant and equipment, and was widely used in all areas related to new airplane construction, including aviation gasoline, light metals, machinery, electrical equipment and machine tools.

Accelerated depreciation was also widely utilized to induce the private sector to invest in factory construction. The Second Revenue Act of 1940 provided for accelerated depreciation up to the full value of the plant, including the cost of procuring the land for all defense facilities built after June 10. The depreciation schedule gave a 20% per annum write-off versus the standard 5%. The tax amortization plan also allowed companies to backdate their write-off to the end of 1939. After Pearl Harbor, the government shouldered a greater amount of the cost of plant construction. Of the $25 billion spent for plant construction, more than one-fourth was covered by these various plans, and hundreds of industries, large and small, participated. Hence, government guarantees drove the war-time escalation, not “the market.”

After a protracted legal debate, the DPC leadership settled upon leasing as the preferred financing mechanism to build and run the plants. The DPC would pay for the cost of building a new plant, and then lease it to the company which would run it, produce the tools, and keep the profits. The company would have the right to buy the plant at the end of the national emergency, but not simply the equipment. A formula was worked out to cover depreciation, amortization, and the cost of leasing the factory and equipment. The purpose of the lease was to avoid possible profiteering by the companies. The DPC would not build the plant and give it to the producers, with little or no guarantees of actual successful operation.

The DPC also created a national pool system to coordinate the purchase of the output through the NDAC and its military procurement arms. The tool industry needed a secure market, working capital, and payment system to engage in the long-term development and production process. The DPC shouldered the risk, first by giving the manufacturers a 30% up-front cash advance to initiate production. Then they created an industry-wide pool to coordinate orders, so that there would not be unsold orders. Finally, they worked with the ordering agencies, especially the military branches, to ensure that payment was made so that orders could be delivered in a timely fashion. The system worked right up to the surrender of Japan in 1945.

The DPC drove the process. It loaned $284 million to the industry in 1941, $1.3 billion in 1942, and another $223 million in 1943, for a total of nearly $2 billion. Thousands of machine shops were started up, either reviving dormant ones or building new plants from scratch. By 1942, the U.S. produced 307,000 new tools, ten times the level of 1938. Overall, between 1941 and 1945, machine tool output doubled in the nation.

With the machine tool issue addressed, the simultaneous buildup in all branches of industry began in earnest.

Tackling the Major Industrial Needs: Airplanes

The first area to be addressed was airplane construction, as indicated by FDR’s May 1940 demand for 50,000 planes a year. The NDAC and its analysts compiled the not-so-simple bill of materials required to construct modern war planes. They were: aluminum, an industry itself in its relative infancy;

magnesium, also in similar shape; steel, oil, and its various derivative products, including aviation fuel, coolants, greases, etc.; airfields, test pilots and real pilots, their equipment, parachutes, and more; and of course, rubber for tires and other uses.

Airplane assembly line during World War II.

The American airplane industry was a boutique operation in 1939. There was modest standardization, but no assembly line or mass production capability. A modern bomber had 5,000 to 10,000 distinctive parts, and had to be constructed from a detailed blueprint, pieced together in a series of assemblies and subassemblies. These parts alone required hundreds of thousands of rivets. The design stage might incur 500,000 hours of planning; and another 30,000 man hours might be required to build a replica from which to test the design, change it, and complete it, so that production could begin.

While all this planning was happening, the parts had to be manufactured and readied for attachment onto the plane. All the planes’ equipment had to be produced and readied for insertion.

Only 13 companies built airplane frames in 1940, and none of those built engines. The most important element of the plane, its engine, had to be developed in parallel mainly in new plants, and delivered to the company overseeing production. Only three companies, at the outbreak of hostilities, even built engines large enough to be used in combat: Wright Aeronautical, Pratt and Whitney, and Allison (a subsidiary of General Motors).

The drumbeat of war transformed the situation. In 1940, Lockheed was a typical small-scale airplane manufacturer and had barely survived the depression. From 1932 to 1938, Lockheed built 300 planes, but in 1938 the British Air Ministry ordered 250 new bombers, and Lockheed rapidly reinvented itself. (Arms, p. 69). It tripled its workforce, and acquired adjacent buildings and more space down the road. It also devised a preliminary assembly line, comprised of sixteen stations where the fuselage would stop and additional parts would be added, provided they were available.

However, the more planes Lockheed built, the faster the tempo, the more coordinated was the delivery of parts, and the more producers and the labor force worked together to innovate new practices. Costs fell by 50%. All the airplane manufacturers replicated this change, which is another example of the increase in Total Factor Productivity, achieved by both technological change, and small creative discoveries along the way.

But the drive to build a modern air force ran headlong into other problems—the shortages of vital materials. There was not enough of everything: aluminum, magnesium, fuel, equipment, personnel, machinery, “the works”. But the key shortage from the get-go was rubber. Without rubber, the entire effort would come to a screeching halt, so to speak.
(to be continued)

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