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"It would be impossible to estimate the value of these works..." Mass Production at Springfield Armory during the American Civil War

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The U.S. Armory in Springfield, Massachusetts, rarely appears in Civil War histories except perhaps as an unexplained statistical wonder. By late 1863, the Armory was the largest single supplier of rifles to Union forces. Springfield Armory workers out-produced over thirty American contractors, making more Army rifles at less cost while providing contractors with gauges, inspectors, and models, even though there were significant wartime private-sector mechanical innovations. This article identifies and explains the factors in the Armory's success, provides context on contemporary American arms production and rifle models, and argues that the Armory's methods and performance were among the first if not the first example of mass production in American small arms manufacture. The relative brevity of the Civil War episode, and the fact that it was not repeated in any comparable way at the Armory until World War II, has obscured its significance in American manufacturing history.

KEYWORDS small arms manufacture, American Civil War small arms, Springfield Armory in Civil War, American Civil War mass production, U.S. Army Ordnance Department, Alexander B. Dyer, James W. Ripley

The Springfield Armory rarely appears in Civil War histories except perhaps as an unexplained statistical wonder. To some contemporary observers, however, the Armory's enormous wartime output inspired words of awe. Writing late in 1863, George B. Prescott

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marveled at not only Armory productivity, but the speed with which wartime demands had been met:

> The United States Armory at Springfield, Massachusetts, is the largest, best appointed, and altogether the most productive establishment for the manufacture of small arms in the world... It would be impossible to estimate the value of these works during...the present Rebellion... [T]wenty-five thousand rifled muskets...are manufactured at this establishment every month... and the works are daily turning out enough to arm an entire regiment...When the Rebels fired on Fort Sumter, the armory was making about one thousand muskets per month...Twenty-six hundred workmen are now constantly employed,—the establishment being run day and night,—and none but the most expert and industrious artisans are to found among them.[1]

Prescott's statistics are accurate, although monthly production varied more than he implied (cf. Figure 1). By the time of his visit to Springfield, the Armory was the largest single supplier of shoulder arms to Union forces, producing weapons whose number and power made a significant difference on the battlefields. This accomplishment took time and effort, despite the Armory's somewhat fortuitous development of a large-scale musket-making system just before the war.

Established in 1794, Springfield Armory had become one of the most productive and best-managed factories in the United States, after forty-five years of managerial innovation, technological improvements, and plant expansion beginning in 1815. Driving much of this development was the U.S. Army Ordnance Department goal of making weapons fully interchangeable, in the belief that such weapons would be easier to repair and cheaper to make. From 1815 to about 1830, army small-arms makers concentrated on pressing problems of weapons quality, and on enforcing common standards for military arms made at national and private armories. Interchangeable manufacture, which proved to be costly and unrelated to rapid field repairs, remained at best an objective for nearly all arms factories during this period. Springfield Armory generally took the lead in meeting Ordnance Department objectives, by creating the technical and managerial basis for large-scale production. Many private armsmakers made more significant technical advances, such as the milling devices and gaging systems with which John Hall is credited with first making interchangeable rifles in the mid-1820s as a contractor at Harpers Ferry Armory in Virginia, the Army's other small arms factory. It was at Springfield, however, that the small arms industry saw the most systematic efforts to combine available technology with cost controls, plant-wide accounting, and plant-wide work rules. In the early 1830s, the department began developing the first standard-issue army muskets intended for fully interchangeable manufacture, a goal finally reached in 1849.[2]

Springfield became the center of what has been called "Armory practice" to make interchangeable, dimensionally-uniform products: extensive use of gage controls and powered equipment, 100 percent inspection of parts, and an elaborate division of skilled, mostly piece-rate-paid labor. It was a demanding system, developed with relative indifference to cost, and required considerable hand finishing of machined parts.[3] Arming a very large infantry force had not been an issue before the Civil War. Springfield's response to wartime demands, previously unexamined in any detail, [4] may have been among the first examples of American mass production of firearms.

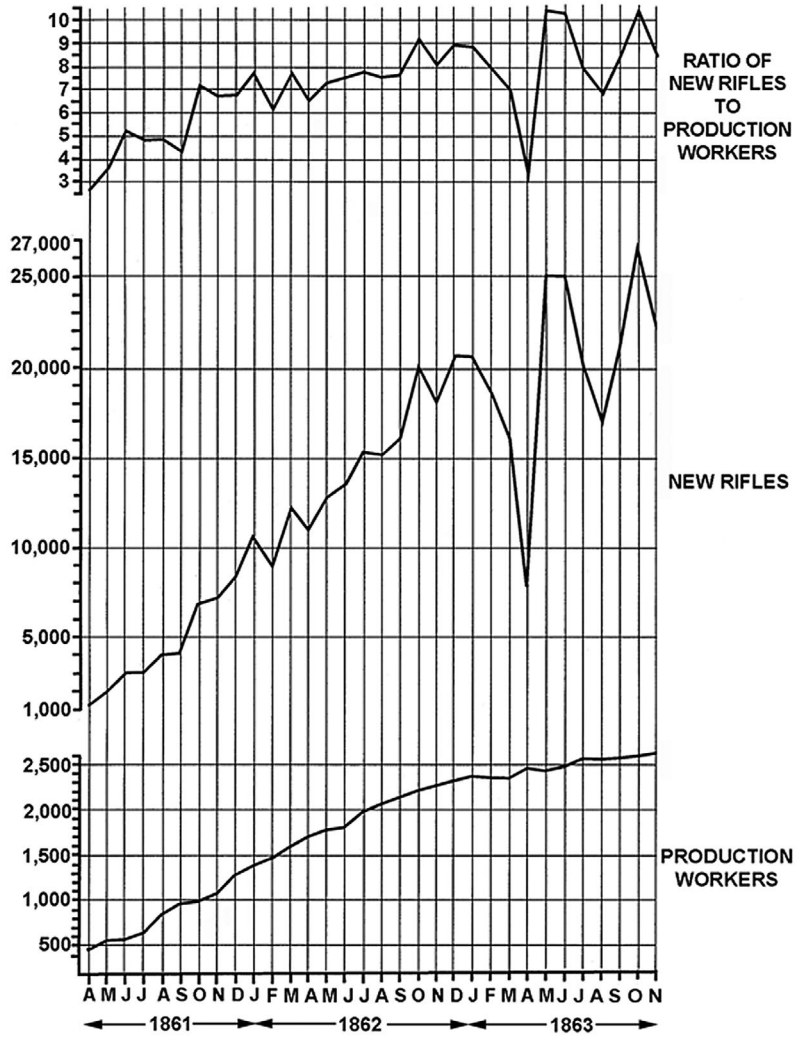

FIGURE 1. Monthly variations in Springfield Armory rifle output & production works, April 1861–November 1863.

These data cover the Civil War months with readily-documented rifle-musket output, compiled by John F. Mitchell, 'Springfield, Massachusetts in the Civil War,' (Ph.D. dissertation, Boston University, 1960) p. 205. Production workers are defined from Payroll Records (RG 156/1379) as all those other than the Master Armorer, carpenters, common laborers, clerks, and draftsmen. Prior to October 1861, production worker numbers are inferred at 85% of total payroll, based on more detailed breakdowns in later monthly returns. Wartime productivity gains were significant, but the proportionately greater increase in production workers than in rifle-musket output per worker suggests the need to train large numbers of men with less experience than those working in the shops in April 1861. The output drop in July 1863 probably reflects disruptions caused by the draft and by temporary problems with barrel quality. The steep output drop in April 1863 is less easily explained, but may reflect in part the conversion to the Model 1863; conversion to the Model 1864 late in 1863 may relate to the drop in November.

Summary of Wartime Federal Shoulder Arms Purchase and Production

The Ordnance Department was unprepared for the war, and in fact had abetted Secessionist plans by transferring arms, equipment, and practical knowledge to Southern armories at the insistence of secretaries of war (and later prominent Confederates) Jefferson Davis and John B. Floyd. Harpers Ferry Armory was destroyed early in the war, and Springfield was not operating at fullest capacity when the conflict began.[5]

To meet large immediate demands for small arms while the Armory increased its scale of operations, the Ordnance Department emptied its arsenals of available M1855 rifle-muskets[6] plus nearly 400,000 older .69 caliber smoothbore muskets, and turned to domestic contractors and European imports. The imports included over 430,000 of the British P1853 or Enfield, very similar to the American .58 caliber rifle-musket, made by private British manufacturers. Not all of the Enfields were interchangeable.[7] Nearly 740,000 other imported weapons were of generally lower quality, but about 83% of these were purchased before July 1862, by which time the Armory and the contractors made most imports other than Enfields unnecessary.[8] Nearly all Union regiments were armed with rifle-muskets by the end of that year. The Confederacy, whose rifle-musket production was a small fraction of the Union's, relied much more heavily on imported Enfields and did not have rifle-muskets in the hands of all its infantry until 1863. By the war's end, Springfield Armory had made nearly 800,000 rifle-muskets, or about 11% more muskets than the factory produced during the preceding 66 years of its operation. This output represented over one quarter of all shoulder arms made or procured for the Army in the war, 42.5% of all domestic shoulder arms produced during the war for the Union, and about 55% of all rifle-muskets made to standard issue patterns (Table 1). If one excludes weapons which were replaced as soon as possible—the lower-quality imports and the old smoothbore muskets—the Armory made at least a third of the shoulder arms with which Union troops were eventually supplied. In doing so, Armory workers out-produced over thirty private contractors, making more Army rifle-muskets at less cost while providing contractors with gauges, inspectors, and models.[9]

The early American private arms industry was heavily dependent on subsidies and contracts from the national government. Until private firms developed enough technical expertise and non-federal demand to limit this dependence, their standards and methods had to reflect Ordnance Department requirements. Early Ordnance Department objectives, and the nature of publicly owned factories, were fundamentally different from those of a more mature private arms industry, however. Private firms by the 1840s profited when they could keep costs low while capturing larger markets with new designs. Just as Springfield Armory was perfecting its methods and improving its plant, private armsmakers and inventors, some adapting selected Armory methods, began to expand the universe of shoulder arms. Private armsmakers did not need to make fully interchangeable weapons, however, so that even the most advanced manufacturers of arms and other metal products had difficulties meeting Ordnance Department requirements for contract shoulder arms.[10]

TABLE 1
SOURCES OF FEDERALLY-FUNDED CIVIL WAR ARMY SHOULDER ARMS

Weapon type	Probable number	%
1. Springfield Armory rifle-muskets	797,936	26.1
2. Contractor-made Springfield-model rifle-muskets	644,439	21.1
3. European shoulder arms other than Enfields	738,266	24.2
4. Enfield rifle-muskets & rifles	436,326	14.3
5. Breechloading carbines	382,959	12.5
6. Other U.S.-made rifles & muskets	52,673	1.7
Totals	3,052,599	99.9

Without wading through mounds of the most primary, untabulated Ordnance Department data, it is extremely difficult to provide accurate figures of shoulder arms which the department either fabricated, or purchased and received, during the forty-eight wartime months. No published compilations of the categories in this table are in full agreement. The most frequently-used list covers the sixty months of 1861-1866 (Letter, Dyer to Stanton, January 23, 1867, RG 156/-), which, with a more detailed breakdown reproduced in Berkeley R. Lewis, *Notes on Ammunition of the American Civil War*, is probably adequate for lines 3 and 4. The same data, amended for carbines and rifles known to have been purchased in 1866, suffice for lines 5 and 6; see U.S. Congress, House, *Ordnance Department Purchases of 1866*. Springfield Armory output (line 1) is based on annual reports for fiscal years 1862 through 1865, an assumption that very little was manufactured between early April and late June 1865, and monthly totals from April 1861 through November 1863 compiled in Mitchell, 'Springfield, Massachusetts in the Civil War,' p. 205. Contractor output (line 2) is from U.S. Congress, Senate, *Letter from the Secretary of War in relation to the cost of manufactures at the National Armory* (Washington: Government Printing Office, 1879) p.75, with correction of sum in original tally. In addition to the more than three million shoulder arms purchased or fabricated, the department began the war with 441,510 muskets, rifles, and carbines of various kinds, as reported in ARCO 1862, in U.S., Ordnance Department, *A Collection of Annual Reports and other important papers relating to the Ordnance Department,* Vol. III, p.448.

The full story of Civil War contract arms manufacture remains to be told, and exceeds the scope of this article. Contractor performance reflected the strength and limitations of the inventive and often very advanced mechanized production techniques of many American industries. Many manufacturers entered the small arms trade for the first time: of some thirty-two firms who delivered at least some of the Springfield rifle-muskets for which they contracted, only six were – or had recently been – makers of small arms. All the contractors required extensive re-tooling and assistance, as well as inspection from Springfield Armory, and all had difficulties meeting their contracts on time. Some of the most successful contractors were machinery manufacturers, such as Amoskeag Manufacturing (textile machines and locomotives), Alfred Jenks and Son (textile machinery), and Providence Tool Company (hardware and machinery). The arms contracts also stimulated development of new machine tools by firms such as Brown and Sharpe, and Pratt and Whitney. Wartime mechanical and organizational innovations in some cases were successfully converted to post-war manufacture of consumer and industrial products.[11]

Overview of Springfield Armory Performance

At the start of the war, President Lincoln appointed Brig. Gen. James W. Ripley (1794-1870) as Chief of Ordnance. Ripley had experience with shoulder arms production, having served as Springfield Armory commandant from 1841 to 1854, during which time he greatly upgraded the plant, and oversaw the first production of fully interchangeable, standard-issue Army rifles in 1849.[12] In August 1861, Ripley installed Capt. Alexander B. Dyer as Springfield commandant. Dyer (1815-1874) was a West-Point-educated artillery

officer who served with distinction in the war with Mexico, and commanded a number of arsenals or forts during the decade before the Civil War. Although lacking in any small-arms-making experience at the national armories, he was exposed to foundry and other cannon-making work at Watervliet Arsenal and elsewhere.[13] Some of the credit for his success belongs to George Dwight, a Springfield resident with experience managing public utilities, who served as the Armory's last civilian superintendent during the first four months of the war.[14]

Springfield Armory originated at a 30-acre Revolutionary War supply and storage depot, on the Springfield town Training Field on a hilltop a mile east of the Connecticut River. To provide waterpower needed for mechanized operations, the government acquired sites on the Mill River, a mile south of the arsenal site, from 1795 to 1809, establishing Upper, Lower, and Middle watershops. Constraints of Mill River topography and power resources made it impossible to consolidate the Armory plant at one site, enforced a permanent separation of the Hill and Water shops, and diffused operations among four principal, geographically separate sites. The net effect of Armory siting was a long-term ceiling on productivity which was not overcome until the introduction of steam power and enlarged shops in the 1840s and 1850s. Ripley's 1854-1860 successor at the Armory, civilian superintendent James Whitney, rebuilt all the waterpowered facilities at the Upper site from 1855-60, raising the dam 10 feet, installing turbines, and building a complex of forging, barrel- and scrap-rolling, and barrel-finishing shops north of the river. Removal of forging from the Hill shops allowed for more consolidation there of polishing and filing of all smaller metal parts. Whitney's work eliminated some trips among shops, and all components traveled only once from the new Watershops to the Hill for milling and filing prior to final assembly (Figures 2, 4, 5).[15]

Faced with the immediate need to expand production in 1861, George Dwight began outfitting unoccupied sections of the new watershops, and prepared plans for expanded or modified facilities on the Hill. His initiative in this regard, along with his early purchases of manufacturing equipment, so impressed Dyer that the Ordnance Department Captain retained Dwight as an assistant superintendent until March 1862 to supervise production and, presumably, much of the construction described below for the first year of the war. Dwight's continued presence probably provided Dyer with a smooth transition, gave him time to learn about rifle manufacture, and allowed him to concentrate on managing the growing work force.[16]

With the help of Dwight and many other civilian managers, Dyer spearheaded an extraordinary expansion of the Armory's factory system. Wartime performance was especially notable for greatly enhanced worker productivity and the speed with which output was increased. For the month before the war began, the *annualized* result of Armory production was approximately 43 rifle-muskets per worker. By the beginning of 1862, the comparable figure was 84 rifle-muskets, a figure which rose to 100 for most months from September 1862 to November 1863 (the last month for which monthly production seems available), peaked at 120 for the months of May, June, and October 1863, and averaged between 100 and 108 for the duration of the war (Figure 1).[17] Armory performance usually matched or exceeded Ordnance Department predictions or quotas. Ripley

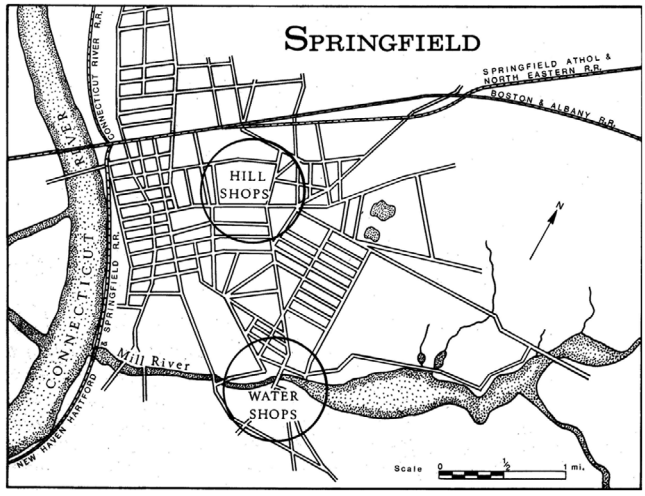

FIGURE 2. Location map of Springfield Armory Hill and Water Shops.
Map prepared by Lyn Malone for Raber, 'Conservative Innovators..', 4.

FIGURE 3. MODEL 1861 rifle-musket.
Image courtesy of Springfield Armory National Historic Site.

revised production goals upwards several times at the start of the war, setting an annual target of 120,000 rifle-muskets in June 1861. Monthly Armory output reached this level in January 1862 and continued to climb. In February 1862, the department estimated that monthly output would reach 15,000 in the following March or April, and that production for the calendar year would amount to 170,000. The monthly figure of 15,000 was not achieved until July 1862, but calendar-year production was nearly 174,000. During calendar-year 1863—a period including payroll, supply, and parts quality problems along with the drafting of some workers—actual production of about 241,000 rifle-muskets lagged behind the November 1862 prediction of 24,000 per month. A year later, the Chief of Ordnance proclaimed the department "..perfectly independent of foreign aid," and predicted the Armory would produce 250,000 weapons during the fiscal year ending in June 1864. The actual output for that fiscal year of over 276,000 was the highpoint of the Armory's 19th-century manufacturing.[18]

There are almost no comparative figures available for private arms contractors making breechloaders or rifle-muskets, but it is unlikely that any American arms manufacturer exceeded the Armory's Civil War productivity except perhaps the highly-mechanized

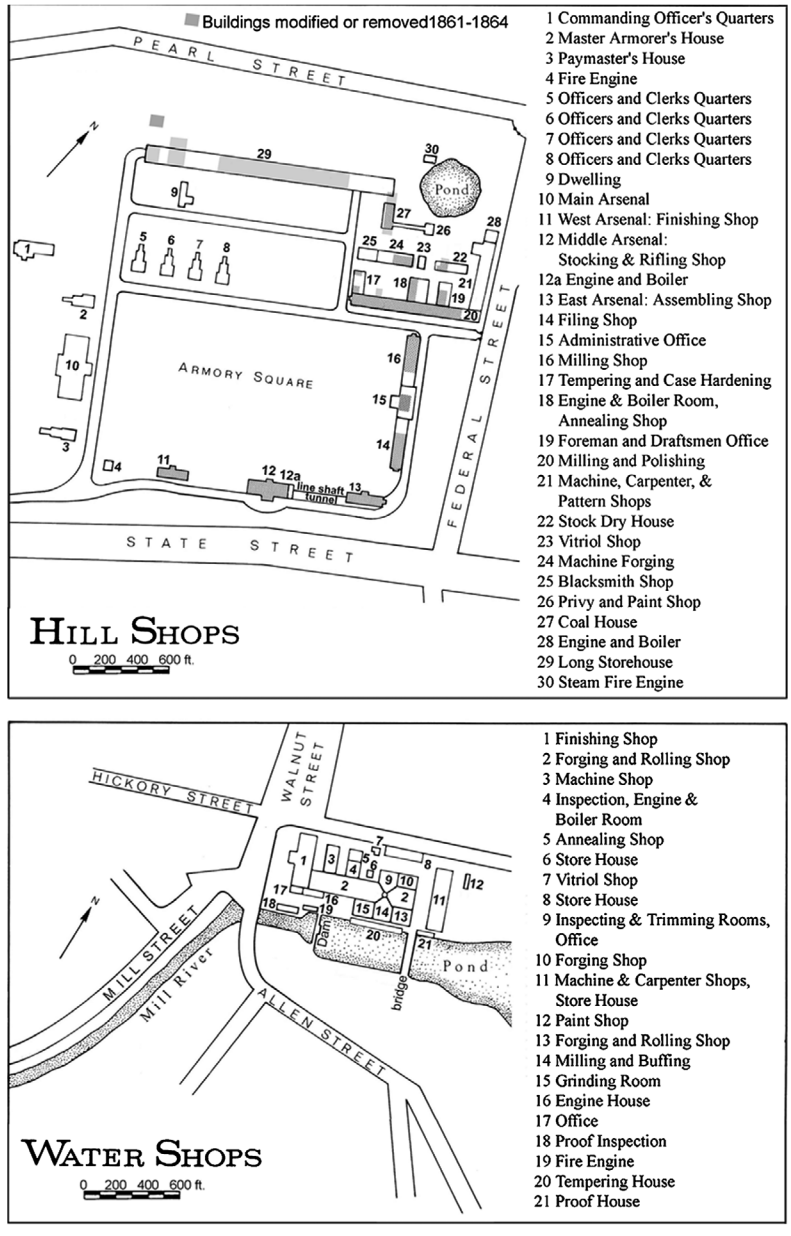

FIGURE 4. Plans of Springfield Armory Hill and Water Shops in 1864.
Modified from map prepared by Lyn Malone for Raber, 'Conservative Innovators..', 5, based on following sources on file at SANHS: Erskine Allin, Plan of Springfield Armory Hill Shops, January 1859; Shedd & Edson, Topographical Plan of the Springfield Armory, Springfield, Mass., April 1864; and Shedd & Edson, Plan of Land with the Water Shops, belonging to the Springfield Armory, Springfield, Mass. April 1864.

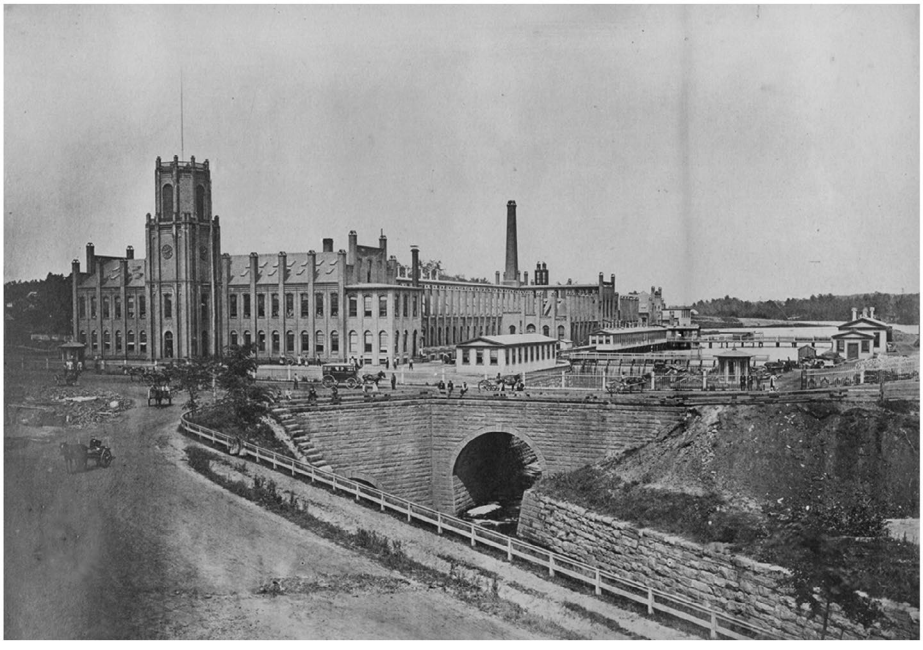

FIGURE 5. View northeast of Springfield Armory Water Shops circa 1875.
The Allen Street Bridge over the Mill River at center, a short distance downstream from the Watershops dam. All buildings north (left) of the river were built 1855-1861, as identified in Figure 4. Buildings south of the river were added in 1875. Image courtesy of Springfield Armory National Historic Site. Alexander MacKenzie, e-mail message to author, November 2, 2016.

Colt Company.[19] The government's wartime expenditure on buildings and equipment—equal to about two thirds of what had been spent during all the Armory's antebellum operations—certainly provided an advantage over most private firms, but does not fully explain Springfield's astonishing results.[20] It is hard to imagine an intact Harpers Ferry Armory, with similar financial resources, providing similar output. Springfield's success, which essentially made Alexander Dyer Chief of Ordnance, was principally the result of:

- minimal changes in weapon models;
- rapid and efficient expansion of plant;
- prior development of a manufacturing system requiring few changes in method or supply of materials, supplemented by large-scale equipment purchases;
- the availability and training of labor for an almost-ninefold expansion of the workforce with a more finely-tuned division of tasks;
- intensive reorganization of factory management.

Focusing On Muzzle-Loaded Rifles

All Civil War rifle-muskets made at the Armory were variants of the Model 1855. About a year before the war, the Ordnance Department approved modified design of this weapon with a plain percussion lock instead of the Maynard primer—by then considered

unreliable—and with several other minor changes in the lock mechanism, hammer shape, and ramrod head. The altered weapon, known as the Model 1861, was approved for manufacture in February 1861. Sudden demands to increase plant capacity, and some indecision on whether to retain the patch box in the stock, delayed manufacture of the Model 1861 until mid-year.[21] This was the model made for most of the rifle-musket contracts, and was produced at the Armory until about February 1863. At that time, the department approved slight changes including a more S-shaped hammer, and narrow barrel bands fastened with screws rather than band-springs. This altered weapon, the Model 1863, was produced at the Armory until very late in 1863, when a return to the use of band-springs and some minor changes were approved for what became known as the Model 1864, the last percussion shoulder arm made for the Army. The models 1861, 1863, and 1864 were interchangeable except for a small number of modified components.[22]

Making essentially the same muzzleloader throughout the war avoided the extensive re-tooling and production delays which Chief of Ordnance Ripley knew had accompanied the introduction of the Model 1842 musket and the Model 1855 rifle-musket. Ripley's resistance to introduction of new models must be seen in part as a means of concentrating on a reliable, powerful weapon with a well-established manufacturing system. As the war began, he correctly predicted that contractors – many of whom made their machine tools in-house – would need considerable time to gear up for rifle-musket manufacture. By the war's end, private firms delivered only 52% of the final adjusted contract numbers for the Army rifle-muskets.[23] For the wartime Armory commandants, minimal re-tooling for shoulder arms also allowed for adequate production of a wide variety of other required material, including model arms, components, and gauges for contract weapons, parts for imported arms, and 15,000 pairs of bits for cavalry and artillery horses. To concentrate on his principal responsibilities, Ripley also relieved Dyer of contract inspection duties in June 1862.[24]

Ripley kept the Ordnance Department focused on making or buying .58 caliber rifle-muskets in the face of considerable clamor for breechloading rifles and carbines, including some repeaters with multiple-round magazines. He resisted attempts to introduce breechloaders into the Army for any non-cavalry units, even on occasions when President Lincoln personally approved of a new weapon.[25] In addition to his concerns about disrupting rifle-musket production by developing a new weapon during wartime, the notoriously stubborn general and other Ordnance Department officers objected to royalty payments on patented designs and to the wide range of ammunition required to use new or imported weapons.[26] They and some line officers also feared that use of the new weapons would lead to uncontrolled fire. Faster to fire than the standard-issue infantry weapon, breechloaders were popular with many Union troops, especially the repeating Spencer and single-shot Sharps models. The government purchased over 380,000 breechloading carbines for cavalry units. Private or state funds were used to obtain thousands of breechloading rifles for infantry regiments, but Ripley's resistance helped restrict federal wartime rifle purchases to some 22,000.[27] Some historians have seen his attitude, which contributed to his ouster as Chief of Ordnance in 1863, as an inexcusable contribution to the length of the war.[28] With the advantage of hindsight,

however, performance as well as production issues make his stance seem not only understandable, but even wise until the North gained the upper hand.

Privately-produced, patented breechloading shoulder arms were widely available by the time of the Civil War, and several antebellum secretaries of war believed their military use was inevitable.[29] Breechloaders could not only fire much faster than rifle-muskets, but they could be loaded from a non-standing position and were not vulnerable to multi-cartridge loading by battle-distracted troops. In 1858, Ripley supervised Ordnance Department breechloader trials to consider possible conversion of rifle-muskets, and the investigating board rejected their possible use as a service arm, finding most had less range, power, reliability and accuracy than the Army issue weapon.[30] Major technical problems included creating a tight seal at the breech against the gas and even flame which could erupt from paper-wrapped cartridges, and designing a mechanism that would not become inoperative because of fouling by powder residue. Of breechloaders available then or during the war, only the single-shot Sharps rifle and carbine combined a good seal with a paper cartridge powerful enough to match the Army muzzleloader's effective range of over 600 yards. Most breechloading carbines had effective ranges of about 150 yards, including those using metallic cartridges.[31] The development of expansive, or metallic, cartridges finally made breech loading practical, as the expansion of the cartridge case against the walls of the chamber made a practical gas seal. Many individuals in Europe and the United States were involved in the development of the metallic cartridge prior to the war, including D. B. Wesson (of Smith & Wesson) and B. T. Henry, who developed a metallic cartridge and repeating rifle for the New Haven Arms Company (later, Winchester Repeating Arms).[32] These were rimfire cartridges too weak for high-powered charges, however, which restricted the range of even the fastest, multiple-shot carbines like the Henry and the Spencer. Cartridge improvements with center-fire high-powered charges did not appear until after the war. Speed was thus hardly the panacea claimed by Ripley's critics.[33]

Availability of wartime breechloaders was at least as critical an issue as their effectiveness. Study of periodic Armory production, design, and re-tooling episodes from the 1840s to the early 20th century strongly suggests that introducing a new standard model shortly before or at the beginning of the war would have denied Union infantry adequate shoulder arms for several years. It would have been virtually impossible to increase and sustain Armory production as Alexander Dyer did if rifle-musket production had been accompanied by breechloader development and phased-in production. With the loss of Harpers Ferry Armory, Springfield was not only the government's only rifle plant, but the largest rifle plant in the United States; interrupting production there before Gettysburg would have been a gross miscalculation. Even if Ripley had devoted all shoulder arms efforts outside Springfield Armory to breechloaders, there were few Union rifle-makers capable of large-scale breechloader production, and probably none capable of overseeing production at plants previously used for other purposes, as Dyer's staff did. Abraham Lincoln's plans for a new armory at Rock Island, Illinois were far too slow abuilding to contribute any weapons during the war. Of some nineteen American breechloader makers active during the Civil War, only four turned out more than 20,000 weapons,

and half produced less than 10,000. Production problems delayed introduction of large numbers of breechloaders until 1863, by which time Springfield had turned out over 213,000 wartime rifle-muskets and developed a capacity of about 200,000/year.[34] Ripley's refusal to test breechloaders may have inhibited the eventual selection of a new Army standard weapon, but his approach to wartime production was not the technologically backward one sometimes perceived by historians.[35]

Expanding the Factory

Management under James Ripley and James Whitney from 1841 to 1860 left the Armory in excellent condition to meet the wartime production challenges. Dwight and Dyer needed only modest additions at the new Watershops. They consolidated all work on barrels here and expanded the forging and grinding areas during the first year of the war, added gas lighting by the fall of 1861, and for the first time installed steampower at this site to meet heavy wartime demands and potential shortages of water supply. Soon after a penstock burst in September 1861, Dyer installed a 60 hp steam engine which was upgraded twice leaving the Watershops with a 200 hp installation by June 1863. Steampower enhanced but did not replace the mechanical power provided by water-driven turbines, however, and Dyer remained concerned about water supply throughout his tenure as commandant (Figures 4-5).[36]

As discussed below, there were large purchases of new machinery in 1861 and early in 1864. To accommodate additional equipment and intensify use of increasingly crowded shops, Armory managers refitted older buildings and added new workspace. During the first months of the war, Dwight converted all three arsenals on the south side of Armory Square for manufacturing, adding third stories to the East and West arsenals for respective use as assembling and finishing shops, and mechanizing the Middle Arsenal as a stocking and rifling shop with a 60 hp Corliss engine. By April 1862, the three two-story structures on the east side of the square were combined as a single building used for milling and filing, powered by a 60 hp engine moved from the Watershops.[37] Use of the arsenals allowed for expanded milling, polishing, and tempering operations in the pre-war machine shop at the northeast corner of the square. By June 1863, Dyer expanded this shop with annealing, tempering, and case hardening facilities, and added at least one 60 hp steam engine; the original 1843 30 hp engine in this shop may have remained through the war, or another 30 hp engine may have replaced it. He also erected a row of buildings to the north for stock drying, machine forging, and blacksmith work, and greatly extended the stock blank storehouse begun in the 1840s. To use the new machinery acquired early in 1864, Dyer added a third story to the shops on the east side of Armory Square, and built a new two-story, 225x35-foot addition to the milling shop complex stretching north along Federal Street. The new structure, powered by another steam engine at the north end, housed a machine shop, a carpenter shop, and a pattern shop (Figures 4, 6).[38]

While it is not clear how much plant arrangements added to the enormous increases in output, the re-distribution of tasks among shops suggests that Dwight and Dyer achieved greater rationalization of shop arrangements, with spatial arrangements

FIGURE 6. View southwest of Middle and West Arsenals at Springfield Armory Hill Shops circa 1870. Middle Arsenal, at left, was mechanized as a stocking and rifling shop in 1861. At this time, a third story was added to the West Arsenal and the building was set up as a finishing shop (See Figure 4). Image courtesy of a private collection.

more closely matching the order of production. As part of his increased control over all aspects of plant management, Dyer forbid movement of machines except by shop foremen as sanctioned by the Master Armorer with Dyer's approval.[39] He also acted early in his tenure to minimize any delays due to fire, outlawing smoking in the shops and forming worker fire companies. In response to the only two fires during the war—in the Hill polishing shops and at a Watershops storage shed, both relatively minor events in 1864—he added more fire engines and an "aqueduct" on the Hill from a cistern built in 1850.[40]

Supplies, Tools, and Manufacturing

Of the factors contributing to the Armory's wartime performance, none was more important than the managers' abilities to expand an existing production system with little need for re-tooling or new types of equipment. A relatively mature machine tool industry, encouraged by wartime contract opportunities, supplied the Armory with additional machines, although sometimes with delays and cost disputes. The well-established metal-forming companies of the Connecticut Valley region, along with a few from Trenton and Philadelphia, gave the Ordnance Department a nearby base of equipment supply free from most imaginable wartime interruptions. During the expansion of the Armory's shops, the antebellum gauge-controlled methods of Armory practice also allowed Dwight and Dyer to contract out the manufacture of many musket components to a wide network of private machine shops and armsmakers in the New England and Mid-Atlantic

regions. Until at least the Spring of 1862, some of the Armory's output included assembly of muskets with purchased parts. At various times, contractors supplied some of all Armory musket parts except the stock. Large-scale purchases of equipment and weapons parts were a new wartime practice at the Armory, and Ordnance Department managers sometimes struggled to assign contract values to things previously made in Armory shops. Contracting for parts was probably necessary while the Armory had the simultaneous tasks of supervising and inspecting the work of rifle-musket contractors, making spare parts for foreign-purchase weapons, and expanding itself to meet rifle-musket quotas.[41]

Armory managers usually procured supplies of tools and raw material other than barrel iron and steel without great difficulty. Ohio remained an important supplier of walnut stock blanks through the Civil War. Winter conditions sometimes delayed rail deliveries.[42] In 1865 a typical log was about 2 feet in diameter and 12 feet long, and would yield from 60 to 100 stock blanks, depending on how much defective wood it contained.[43]

For critically-important supplies of files, English makers from Sheffield remained dominant although American firms captured some of the wartime Armory file business. By the end of the war, the Armory had on hand some 360,000 files, enough for 20 years of peace-time production.[44]

When the war began, Springfield was in the awkward position of being entirely dependent on English sources for gun iron as well as steel. Abram Hewitt, whose Cooper, Hewitt & Company operated the Trenton Iron Company, bought English iron for the Armory at the Marshall works. In the Fall of 1862, he convinced the Ordnance Department and the Secretary of War that he could make iron of comparable quality if guaranteed a price no less than that paid for English iron. He succeeded in making usable iron only after a visit to Birmingham and much technical difficulty, and by the Fall of 1863 secured all orders for Springfield Armory barrel iron. Within a few months of this contracting coup, the Armory and the Remington Company found deficiencies in the Trenton iron for barrels, but this domestic source continued as Springfield's sole iron supplier through the war and beyond.[45] Trenton Iron Company's investment was ultimately not a good one, however, since the market rested on Springfield's determination to continue to use an obsolete material long after the private arms industry had adopted steel barrels.

Armory metalworking and woodworking capabilities were greatly expanded during the war. While the complete story of Springfield's machinery purchases remains undocumented, there were at least two major episodes of equipment buying. Superintendent Dwight ordered nearly forty major pieces of equipment plus milling machine components during the first three months of the war,[46] and Dyer evidently ordered much larger purchases by late 1863-early 1864. There are two summary sources of information about machinery used at the Armory after the expansion to wartime production: a "Statement of Machines and Manufacturing Capacity at Springfield Arsenal" for January 1, 1864 (see Table 2);[47] and a list prepared by Dyer of the machinery and labor required for an armory to make 500 rifle-muskets per 10-hour day at about the same time in 1864.[48] Since Springfield was producing about 900 rifle-muskets per day in 1864 by working two shifts, the latter list should show very nearly the machinery actually in use at the height of wartime production. There are some discrepancies between the lists that suggest that they

TABLE 2
MACHINERY AT THE SPRINGFIELD ARMORY ON 1 JANUARY 1864

Forging:	
36 Trip hammers, 75 lbs average	2 Rolls for bending sheet iron
43 Drop hammers, 300 lbs average	5 Rolls for barrels
126 Smith's forges	13 Rolls for drawing iron setts
2 Rolls for curving scalps	12 Fan blowers, 5 psi
Metal machining:	
34 Rifling machines	2 Machines for tapping barrels
35 Hand lathes, fixed rest	4 Bayonet socket lathes
2 Broaching machines	1 Sticking machine
1 Stamping lock plates	1 Shaving machine
53 Profiling machines	2 Horizontal drills
50 Drilling and boring machines	74 Barrel boring machines
3 Bayonet boring machines	11 Cone machines
7 Bayonet polishing machines	3 Barrel staighteners
8 Barrel polishing machines	2 Ramrod polishers
25 Barrel and breech turning lathes	
282 Milling machines for components	
7 Hand planers 15" wide x 12" high x 24" long	
29 Power planers, lenghts 3 to 14', various heights and widths	
2 Machines for cutting threads on butt and guard screws	
- Machines for milling and threading breech screws	
3 Plain slotting machines, average 8 1/2" length of cut	
1 Punch, will make 3" hole in 5/8" iron plate	
20 Punches, will make 2" hole in 1/2" iron plate	
1 Screw cutting machine 2" diameter by 20' long	
5 Screw cutting machines, 0.2 to 1" diameter by 6' long	
13 Slide rest lathes for turning only, 2" diameter, 2'6" long	
67 Slide rest lathes for cutting screws, 2" diameter, 2'6" long	
24 Slide rest lathes, double geared, 3" diameter, 4' long	
Stocking:	
14 First and second turning	1 Turning between bands
2 Bedding butt plates	4 Barrel bedding
3 Boring stock for ramrod	2 Guard bedding
1 Grooving for ramrod	2 Lock bedding
2 Sawing and facing	2 Sawing and shaping butts
1 Turning on bands	
Other:	
10 Circular saws, 10"	1 Vertical saw, 12" stroke
2 Cutting arms chests	2 Centering machines (wood)
2 Boring for arms chests	4 Force pumps
1 Spotting machines (wood)	2 Universal gear cutting machines
12 Grinding machines for plane surfaces	
1 Planing machine 24" wide x 4" high x 144" long (for wood)	
2 Planing machines 24" wide x 18" high x 336" long (for wood)	
1 Double-geared threading machine for gas pipes	

Machines on hand and on order are listed separately in the "Statement" but are combined in this table.

'Statement of Machines and Manufacturing Capacity at Springfield Arsenal' for January 1, 1864. This version of the data appears in Raber et al, *Forge of Innovation*, p. 230.

may have been hurriedly drawn up. For example, both lists specify 34 rifling machines, but while the "Statement of Machines…" includes 36 trip hammers and 74 barrel boring machines, Dyer's list calls for 51 and 37 of these machines, respectively. We will assume that the "Statement of Machines…" (Table 2) is the more accurate representation of the machinery actually in use.

Comparison of the 1075 pieces shown in Table 2 with a list of 187 machines used in 1851 gives some idea of the magnitude of wartime expansion.[49] More machines are intended for specific tasks on the 1864 list than the 1851 list, such as those used in 1864 for tapping barrels, milling and threading breech screws, and making bayonet socket lathes. Large grindstones shown for 1851 were no longer in use in 1864. It appears that Armory workers still built much of their own machine tooling in 1864, since there would be no direct work for the 29 power planers or the gear cutters listed in Table 2 in making small arms. To see the change in the intensity of machine use from these lists, allowance should be made for the increase of the rate of production from about 500 muskets per week in 1850 (including an allowance for muskets converted from flint to percussion) to 3600 per 60-hour week in 1864, an increase by a factor of 7.2. The number of stocking machines increased by only 2.4 times and the number of millers by 5 times. Thus, either the machines in use in 1864 had a much larger production capability than those used in 1850, or the machines present in 1850 were not working to full capacity. With the exception of a few advances in method, the most likely explanation is that the more intensive wartime division and management of labor, discussed below, allowed for more output per unit of machinery.

The small changes in percentage distribution of labor among different tasks before and during the war, reflected in work return and payroll records, confirm that Armory managers increased wartime production primarily by expanding on existing methods and techniques (see Table 3). These data also identify improved operations. Payroll records for January 1860 and January 1864 indicate that the proportion of labor devoted to forging decreased from 15% to 5% and thereafter remained low, reflecting new mechanization in the forging process.[50] Harvey Waters of Millbury demonstrated in 1861 how to forge bayonets by rolling them in chilled iron rolls rather than under a trip hammer. The Armory adopted this technology, using a roll with nine grooves. Also in 1861, Lamson, Goodnow & Yale of Windsor, Vermont built ten drop hammers for the Armory to replace some earlier models that were "of a rough character."[51] Table 2 shows that by 1864 drop hammers, which are used for closed die forging, had become more numerous than trip hammers. This investment in drop hammers substantially reduced the labor that had to be devoted to forging components before they were machined and filed to finished form.

Two new machining techniques appeared between 1860 and 1864. The most important was profiling, by 1864 the fourth most numerous type of metal-cutting machine (Table 2). Profiling first appears in our payroll record samples at this time as well (Table 3), although it represents only 1% of the total labor. F. W. Howe designed a practical profiling machine for Robbins & Lawrence in 1848, reportedly used at Springfield in 1849.[52] The payroll records, however, show that only very limited use was made of this technology before 1864. The other new technique was broaching, used on the middle and upper bands.[53]

TABLE 3
DISTRIBUTION OF TASKS IN MAKING SMALL ARMS AT SPRINGFIELD ARMORY

Task	1811	1820	1830	1840	1843	1850	1860	1864	1878	1898
Roll	-	[1]	1	4	1	1	*	*	1	1
Forge & draw	[18]	20	20	16	12	18	13	5	2	5
Weld	[29]	4	8	7	5	5	2	4	2	0
Mill & slit	[3]	3	3	4	9	7	12	14	20	20
File	[23]	30	27	26	15	29#	23	23	12	11
Grind	[14]	5	4	3	2	5	2	1	3	1
Profile	0	0	0	0	0	0	0	1	5	11
Bore	[5]	4	4	2	4	5	5	8	7	0
Rifle	[0]	0	0	0	0	0	1	1	1	<1
Turn	*	2	3	2	4	4	2	1	3	2
Drill	*	1	2	2	9	4	6	3	7	11
Straighten	*	<1	*	*	*	*	*	1	1	2
Heat treat	*	5	1	1	2	2	3	3	5	2
Polish & buff	[8]	5	4	5	5	7	6	5	4	5
Blue & pickle	*	*	<1	*	*	*	*	*	3	1
Assemble	*	*	*	*	4	1	2	1	1	3
Stocking	*	13	13	10	9	6	7	9	10	9
Inspect~	*	*	<1	7	3	2	*	5	8	7
Miscellaneous	[0]	6	7	11	16	4	16	15	5	8

This table shows the percentages of direct labor in making a musket or rifle devoted to each class of work listed. Data are from the payroll and work returns and were sampled for the month of January for each year listed. The 1898 figures reflect work on the Krag-Jorgensen magazine rifle, selected as the Army's standard shoulder arm in 1893.
* = no data
[ ] = Data are for the Water Shops only.
= 58 men filing hammers (for conversions) not counted.
~ = Master Armorer, Assistant Master Armorers, and foremen not counted.
"Miscellaneous" = all tasks not enumerated above.
Raber et al, *Forge of Innovation*, p. 199.

Dyer's list of requirements to make 500 rifle-muskets per 10-hour day described each operation used to make each part, showing the amount of hand and machine work done. Table 4 summarizes his data for the tumbler. The machinery used to make this part cost $3950 and the total labor cost for 500 tumblers was $53.08. The actual operations carried out by the different machines are not specified, but the first milling was probably hollow milling of the arbor and pivot, and the second and third milling probably the shaping of the perimeter of the tumbler. Filing was required to bring these dimensions to gage. The distribution of hours (and costs) are 7% (6%) for forging, 41% (45%) for machining, and 52% (49%) for filing. Thus, despite the use of eleven different types of machine tools in making the tumbler, filing remained the largest expense and represented the greatest number of hour of labor in its manufacture. It also demanded the highest grade of labor.[54]

Hand-tool work was also critical in three stock "fitting" operations and in "completing" the stocks: 68 men are so designated in Dyer's hypothetical list of requirements out of a total of 93 needed to make 500 stocks per day. Mechanized stockmaking here was based largely on the equipment designed in the 1840s and early 1850s by Master Machinist Cyrus Buckland, replacing the first generation of stocking equipment installed by Thomas Blanchard in the 1820s. Buckland's equipment was widely praised, and as

TABLE 4
OPERATIONS IN MAKING 500 TUMBLERS/10-HOUR DAY IN 1863.

Operation	Tools Used	Tool Cost	Man Hours	Piece Rate	Class of Artificer
Block	1 Trip hammer	$400	10	0.00375	Ordinary blacksmith
Drop swage	1 Drop hammer	600	5	0.0025	Ordinary blacksmith
Anneal				Day labor	
Trim	1 Power press	600	1	0.0005	
1st mill	3 Millers (small)	300	20	0.0085	Ordinary mechanic
Drill	1 drill press	200	10	0.0044	Ordinary mechanic
2nd mill	2 Millers (large)	400	10	0.0056	Ordinary mechanic
Free	1 Miller (small)	300	10	0.004	Ordinary mechanic
3rd mill	4 Millers (large)	350	20	0.011	Ordinary mechanic
Slit	1 Tumbler slitter	300	8	0.004	Ordinary mechanic
Square	1 Miller (small)	300	10	0.005	Ordinary mechanic
Countersink	1 Drill press	200	3.5	0.0034	Ordinary mechanic
Crown pivot	(same as countersink)		2	0.0015	Ordinary mechanic
1st tapped	(Bench work)		2.5	0.002	First class mechanic
File	(Bench work)		120	0.052	First class mechanic
2nd tap	(Bench work)		3	0.0017	First class mechanic
Temper				Day labor	

See note 46 above.

produced by private manufacturers was sold to foreign armories, but left considerable hand work needed to complete a stock.[55]

Robert Gordon and Carolyn Cooper have summarized Civil War stockmaking at the Armory:[56]

> Stockmaking remained largely unchanged in method through the war and after. Buckland's second-generation machines lasted a long time, and the same basic types of stocking machines used in the 1850s appear in lists made in 1864 (Table 2) and 1872,[57] with the addition of one machine for boring the closed channel for the ramrod, and one for shaping the ends of butts which appeared in 1864 lists and disappeared by mid-1872. The estimated prices for the stocking machines in 1864 ranged from a low of $150 for a "centering" machine (used in preparing the stock for subsequent lathes) to a high of $2,550 for a lock-bedding machine.[58] The Armory had to increase its number of stocking machines in order to expand its output during the war. By this time, outside machine-tool companies had grown up that were able to produce several kinds of stocking machines; the Armory did not have to build its own.[59]
>
> Since different stocking machines took different amounts of time to complete operations, a smoothly-running production line would need more of some kinds and fewer of others. In [Dyer's hypothetical list], one can find the proportions that would be needed for a balanced production line to make 500 muskets in a ten-hour day. For instance, two men operating one machine each to bore the closed ramrod channels were required to keep up with one man operating a single machine to cut the open ramrod grooves. Twice as many (four) lathes for rough-turning the butt were needed as for rough-turning the tip of the stock (two), but one man could operate two of the butt-turning lathes at a time, so only four "ordinary wood workmen" in all were required for rough-turning. Since they ran more slowly, twice as many (twelve) lathes were needed for finish-turning as for rough-turning (six), but only two "first-class wood workmen" were required to tend all twelve. Similarly, twice as many men and machines (two each) were needed for lock-bedding as for guard-bedding (one each).[60]

Expanding, Retaining, and Training the Labor Force

The promise of wartime military contracts created something approaching full employment in the plants of many armsmakers, machine shops, iron works, and other industries in the Connecticut Valley region. Higher wages and a shortage of skilled labor soon confronted virtually all managers of large shops. Early in his tenure, Commandant Dyer solicited mechanics from the demolished works at Harpers Ferry. He complained of small-arms contractors hiring away some of his men early in 1862, and later that year imposed a penalty of a half month's wages on anyone who quit with less than two weeks notice. His successor, Major T.T.S. Laidley— who came from Frankford Arsenal after Dyer became Chief of Ordnance in September 1864—continued having problems finding stockers, finishers, and tool makers until the end of the war.[61] At the same time, armory managers rarely, if ever, advertised publicly for jobs,[62] and had relatively little trouble expanding the total workforce from 545 in April 1861 to a peak of 2992 in April 1864, confirming the Secretary of War's assertion that the Armory was "...in the midst of an industrious and ingenious people, where competent workmen can always be attained without difficulty."[63] Armory managers met the challenge of increasing output in a tight skilled-labor market by paying proportionately more for experienced mechanics, training less skilled men to do a narrower range of tasks, and adding a second shift.

George Dwight resisted regular night work, arguing that "there are difficulties in the way of working double sets of men and much confusion and injury to machinery and tools would be the result." Instead, he tried to deploy gas-lit night work only in shops where parts production was lagging.[64] By July 1861, this policy resulted in some shops working 24 hours a day, while others were open 14 to 16 hours.[65] Some of this disparity in hours may be attributed to the flurry of simultaneously adding equipment, men, and workspace to a crowded Armory. Dyer quickly decided to enforce two regular shifts, issuing an order ten days after starting his command that there would be two shifts seven days a week, each for ten hours of work plus meals. He limited confusion between the work of two shifts, principally by minimizing the number of machines on which any one man worked. Except for a few holidays, and brief periods between shifts, the Armory remained open 24 hours a day until Dyer left to become Chief of Ordnance. In late September 1864, with the diminished press of rifle-musket quotas, Sunday evidently reverted to a day of rest.[66]

When first ordering two shifts, Dyer's only concession to disrupting workers' lives with night work was a monthly alternation of the day and night shifts. He at first insisted on no extra pay for night work, but later—probably by the end of 1861—he bent to the force of labor market conditions and paid the night shift time and a half, as was becoming more common in the wartime arms industry.[67] Along with the certainty of full-time employment, wages remained Dyer's greatest strength in attracting workers, as the Armory evidently continued to pay higher average wages than private armsmakers in Connecticut or Massachusetts.[68] Nominal Armory wages increased greatly during the Civil War, rising 15-20% from December 1863 to July 1864, with a revision of the piecerate tariff every three months.[69] Deyrup has made the only detailed attempt to assess wartime Armory

wages. She noted especially sharp increases during 1861 and 1862, and concluded that the monthly mean wages of all Armory workers increased about $30. At the same time, wartime inflation of living costs resulted in reduced real wages, doubtless contributing to worker complaints and even departures when payment was late.[70] Payment delays of three or more months were frequent, with rippling effects for the regional economy in which the Armory was the paramount manufacturer.[71] The Armory's role in this regard was so critical that local banks advanced $100,000 in April 1862 towards an even larger wage balance due.[72] Dyer wrote anxiously of late wages to the Chief of Ordnance for long periods throughout his tenure, noting that men threatened to leave.[73] Armory payroll records indicate, however, that the only time such threats offset the attractions of Armory employment were between approximately July and November 1864. The other threat to retaining Armory labor forces was the first round of national conscription in July 1863, which drafted several hundred workers.[74]

It appears that the higher wages created by strong demand for small-arms workers throughout the industry tended to diminish labor conflicts with Armory management. Aside from increased absenteeism and occasional rowdiness during periods of wage payment delays, there was only one reported labor dispute within the greatly-expanded workforce. Dyer thwarted a threatened strike by the barrel rollers in March 1862 by securing a supply of privately-produced barrels and arranging for possible new workers if needed.[75] The barrel rollers were atypical, however, in being among a small group of inside contractors. The same pressures driving Armory managers to contract for parts during the first year or so of the war also allowed inside contractors to weld, grind, bore and sight barrels and to mill and turn bayonets. This was the only divergence in Armory history—other than Thomas Blanchard's work in the 1820s—from a policy precluding such arrangements. With the training of new workers, Dyer was evidently able to eliminate all inside contractors except those for barrel rolling by September 1862.[76] Barrel rolling remained such a specialized technology that George Dwight felt compelled to bring back William Onions, the Englishman who set up Springfield's 1859 rolling works, in July 1861. Onions was clearly identified as a contractor in payroll records through November 1861, afterwards working as an assistant foreman or foreman but evidently hiring his own workers. By July 1863, barrel quality was becoming an issue, and, for what appears to be the first time, Dyer ordered that all barrel rolling procedures be strictly followed and that rollers and other barrel workers be debited for condemned work.[77]

The wartime expansion of the regional small-arms industry quickly absorbed all experienced artificers and mechanics, and the Armory paid proportionately more for such men. Deyrup's analysis of Armory wages concluded that modal wages of "highly skilled" workers increased sixty percent in this period, far more than the (unidentified) modal increase for "semi-skilled" workers.[78] To make up for the lack of experienced men, Armory managers essentially created more of them through on-site training. Entry-level "learners" were paid by the day, and probably account for the day-rate workers scattered in payroll records among far more numerous piece-rate men doing the same jobs.[79]

Training almost certainly focused on one or two machine or filing operations per worker, in line with a near-quadrupling of production-related occupations over the antebellum

division of labor. Payroll records indicate that the 113 clusters of operations or occupations identified in January 1860 had ballooned to 437 by January 1864, to make essentially the same weapon. This suggests that Armory managers were dedicating more machine tools to single purposes, which reduced the need to change tooling and enhanced the flow of work. Stockmaking—the earliest set of operations established on this basis—was probably the only branch in which the division and specialization of labor achieved in the 1850s remained about the same through the war. Two operations, "first turning tip of stocks" and "fitting on tips," had been added in 1864 to the seventeen tasks identified in mid-1859.[80]

Despite a more finely-graded division of labor, reliance on less-skilled men required proportionately more artificers to achieve the tremendous increases in wartime output per production worker. During the first year of the war, this output ratio increased by a factor of 2.5, but was accompanied by a 3.7-fold rise in the number of production workers. At the apparent peak of per-worker output in May 1863, the monthly total of 10.4 new weapons per worker represented a 4-fold increase over output in April 1861, but required 5.2 times as many production workers (Figure 1). By this time, Springfield Armory was among the largest mechanized factories in the world, with perhaps a more finely-tuned division of labor than seen at most if not nearly all other plants.

Reorganizing Factory Management

The Civil War presented the Springfield Armory with its first significant military challenge, involving a scale of operations at which Armory managers faced essentially modern supervisory problems. Expanding the plant, and training a larger work force to use an existing manufacturing system more intensively, were critical components of the Armory's wartime success. These ingredients alone would not have sufficed, however, without numerous changes in plant and shop management.[81] Antebellum Armory factory management was probably the most advanced among American metal-forming and machining factories, but relied on many unwritten rules and included considerable autonomy among shop foremen.[82] While generally effective with a relatively small, experienced workforce and a modest Army to supply, this system was evidently too imprecise to meet prolonged demands for maximum output. After Dwight's focus on plant enlargement, Dyer and his chief aides immediately began to tighten and standardize rules of requisition, accounting, inspection, shop management, and discipline.

The Ordnance Department required frequent reports of post operations and expenditures, leaving commanding officers with broad discretion in running their installations.[83] Wartime Armory rules emerged in post orders which helped Dyer impose a more military command structure on an essentially civilian management system. Despite the addition of a military guard detachment in 1861 there was no administrative use of junior officers in the shops.[84] A few of Dyer's orders probably reiterated or codified earlier rules, such as those prohibiting loitering, peddling, or newspaper reading in the shops, but most appear to represent changes in kind or degree to existing practice.[85] Dyer probably made most of the decisions, assisted by some of his immediate subordinates like Dwight and Master Armorer Erskine Allin.

During the first several months of his command, Dyer introduced more centralized controls over requisitions, material handling, accounting practices, and hiring of workers. These measures made shop management more uniform and easier for Allin to coordinate, and appear to represent an attempt at comprehensive adjustment of earlier practices. The obligations of shop foremen evidently increased considerably, and clerks or assistant foremen were soon hired to keep up with new recordkeeping duties. In addition to overseeing the efforts of growing numbers of workers, foremen became responsible for keeping ledger-based records covering requisitions, delivered material or machinery, expenditures, and detailed accounts with pieceworkers for debits and credits on material issued, fabrications, scrap, and wastage. Charges for wastage beyond an amount considered appropriate to the task were deducted from workers' pay. To minimize wastage in the forging shops, iron and steel were cut to length before delivery to workers, and piece rates reduced by the cost of cutting the raw material. Foremen were also responsible for assessing charges against workers for tools or machines damaged by inappropriate or careless use. While foremen's responsibilities increased, their autonomy in hiring, firing, or disciplining of workers was reduced in favor of the Master Armorer, who had to approve all such recommendations with the approval of the Commanding Officer.[86] Most post orders between about November 1861 and June 1863 reflect adjustments to Dyer's initial reforms. Tighter controls over material and accounting were imposed in the Spring of 1862, with pieceworkers required to use only government-supplied tools and materials, and foremen required to keep tool accounts for each worker as well as work returns. By the Summer of 1863, the authority of foremen to transfer workers among shops was increasingly restricted and vested with the Master Armorer.[87]

Dyer's later post orders often addressed problems which emerged as a workforce with many less-skilled members grew in size. In September 1863, foremen and inspectors were ordered to check work in progress on machined musket parts more frequently, presumably to prevent faulty work from accumulating undetected until the usual times of inspection. As part of this in-progress effort, new men were hired to relieve inspectors of a responsibility to count parts. In a sharp change from traditional Armory practice of debiting workers for unacceptable work, the Master Armorer was given leave to omit such charges if the spoiled work did not result from carelessness—most likely an acknowledgment that less experienced men needed more help and leeway while reaching desired levels of competence.[88] By May 1864, hiding of bad forged parts became a problem in the Watershops, and Dyer ordered all forged parts to be counted and put in numbered, labeled boxes under control of the milling or finishing shop foreman. Inspectors periodically verified the number of condemned pieces in each box, and any such pieces found missing were charged against those responsible at twice the normal debit value.[89]

Although more rigorous than the accounting and management practices of his antebellum predecessors, Dyer's administrative system retained a more traditional approach to government-produced weapons on issues of cost. Controlling costs at the wartime Armory was a means of minimizing waste and maximizing output, but was not itself a measure of successful operations. The effectiveness of Armory recordkeeping made Dyer's system a useful model, however, when depressed economic conditions in the 1870s

made cost control a more explicit goal in American metal-working industries. Ordnance Department officer Henry Metcalfe, who began his career serving at Springfield from 1870-1875, developed a new cost-accounting system c1880 while at Frankford Arsenal and published the first American book on the subject in 1885. Metcalfe's initial interest in the problem probably stemmed from his department's need in the late 1870s to show weapons costs competitive with those of private manufacturers. He developed a "shop-order system" in which numbered tickets or slips attached to each job accumulated data on all time, labor, and material costs. Sorting these data by job ticket allowed for calculation of indirect as well as direct costs. Variants of Metcalfe's system were applied at the Frankford and Benicia arsenals, and perhaps at other Ordnance Department facilities. While some private managers including Frederick W. Taylor criticized Metcalfe's reliance on slips which foremen and workers had to fill out, Metcalfe's system generated some of the earliest public discussion in American industry of what later became known as scientific management. He suggested minimizing the use of ledgers, which probably continued to dominate Springfield Armory recordkeeping, yet he noted that the germ of his idea derived from his experience at the Armory.[90] Part of the Armory's voluminous controls, which distinguished types of work done in each shop, were based in the early 1870s on slips filled in by each workman noting

> "...in his own language, the manner in which his time was employed. This and the time were copied into the time books, but nothing more was done with the tickets."[91]

Metcalfe dedicated his book to (then-deceased) Col. James G. Benton, who commanded the Armory during Metcalfe's posting there. Given the Armory's much-reduced work force and manufacturing in that era, however, it is unlikely that the recordkeeping was much developed beyond the system in place during the Civil War. Metcalfe's system was probably inspired initially, then, by exposure to the methods Dyer and his managers developed or elaborated to control production. Although the influence of wartime Armory management on later American manufacturing was largely indirect, it presaged the kinds of innovation needed to handle mass production.

Mass Production in Small Arms

Mass production, as distinct from interchangeable manufacture on a large scale, is sometimes associated with mechanisms made with minimal hand-fitting for a mass market, with lower costs flowing from higher worker output. The initial achievement of mass production has often been credited to self-publicized 20th-century makers of automobiles, although it has also been attributed to antebellum makers of wooden and brass clocks. Some would classify Springfield Armory's Civil War performance not as mass production, but as a large-scale application of the "American system of manufacture" or "Armory practice," which is often characterized as the use of gauge-controlled mechanized wood- and metal-working techniques to make products with varying degrees of interchangeability.[92] This view ignores the great increases in worker output and the lowered manufacturing costs achieved by Springfield, as well as the role of war in stimulating

new levels of manufacturing for the equivalent of a mass market. At Springfield Armory, there was an unprecedented combination of "...technological and organizational innovation [which] created a high rate of throughput and [allowed] a small working force to produce a massive output" —Alfred Chandler's definition of a mass production industry.[93] It is hard to see the wartime Armory as engaged in anything other than mass production, among the first if not the first example in American small arms manufacture, in an episode sufficiently out of scale with most later-19th-century American precision industry to at least temper the conventional interpretation that Henry Ford first achieved civilian mass production. The relative brevity of the Civil War episode, and the fact that it was not repeated in any comparable way at the Armory until World War II, has obscured its significance in American manufacturing history. Recent attention to the connections between the Civil War arms industry and 20th-century American mass production highlights the need to understand how the Armory reached its wartime pinnacle.[94]

The Price of Success

By the time Alexander Dyer left the Armory to become Chief of Ordnance, in September 1864, the Union's battlefield and ordnance supply crises were over. The performance and availability of single-shot breechloaders made their permanent introduction into the Army inevitable. Dyer initiated a new investigation of patented models early in 1865, but at about the same time began to consider converting the large supply of unused muzzleloaders to breechloading arms. A successful adoption of master armorer Erskine Allin's loading mechanism using the Ordnance Department's own 1866 development of a center-fire metallic cartridge gave the United States one of the first standard military single-shot breechloaders with such ammunition. Private adaptation of this cartridge into repeating rifle designs contributed to the Army's 1873 acknowledgment that a standard magazine military rifle was a goal. The conflict between selecting the best available model vs. modifying a patent-free government design with established production methods contributed to a prolonged search for a magazine rifle during a post-war generation of diminished military spending. These issues proved to be the dark side of the militarily-correct decision to make only rifle-muskets during wartime.[95]

Abbreviations

ARCO U.S., Ordnance Department, Annual Report of the Chief of Ordnance to the Secretary of War for the Fiscal Year Ended June 30, —.
ARSA Annual Report of Operations at the Springfield Armory. Titles vary, and reports appear in different archival sources, as noted.
RG 156/ Record Group 156, Records of the Office of the Chief of Ordnance, National Archives. Record entry number follows slash.
SANHS Springfield Armory National Historic Site. This refers to material held by the National Park Service at Springfield.

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I thank my colleagues Robert Gordon, Patrick Malone, and Carolyn Cooper for their advice and collaboration in preparing this article, and for years of work on Springfield Armory and many other topics in industrial history and archaeology. Some years ago, Col. Theodore L. Gatchel (USMC, retired) contributed his research on small arms cartridges, and the late John R. McCabe (former curator at Springfield Armory National Historic Site) provided his research on early M1861 production. Current curator Alexander MacKenzie recently provided digital copies of many armory site maps pertinent to understanding Civil War plant expansion, as well as several photographs used in this article.

Notes

[1] G.B. Prescott, 'The United States Armory.' *Atlantic Monthly* 12 (1863): 436-51.

[2] For an overview of this period, see Michael S. Raber, 'Conservative Innovators, Military Small Arms, and Industrial History at Springfield Armory, 1794-1918', *IA: The Journal of the Society for Industrial Archeology*, 14, 1 (1988),10. On Harpers Ferry and private innovations, see, e.g., Merritt Roe Smith, *Harpers Ferry Armory and the New Technology* (Ithaca: Cornell University Press, 1977), pp. 201-212; and E.G. Parkhurst, 'Manufacture by the System of Interchangeable Parts,' *American Machinist* 24 (1901):39-43.

[3] Raber, 'Conservative Innovators..', p. 12; for the importance of hand finishing in making interchangeable small arms, see Robert B. Gordon, 'Who Turned the Mechanical Ideal Into Mechanical Reality?,' *Technology and Culture* 29 (1988): 744-778.

[4] Felicia J. Deyrup's discussion of the Civil War among Connecticut Valley arms makers, in Arms Makers of the Connecticut Valley, *A Regional Study of the Economic Development of the Small Arms Industry, 1798-1870*. Smith College Studies on History, vol. 33, (Northampton, MA: Smith College, 1948), Chapter XIII, focused on Springfield Armory, as did her entire monograph, because of the far more abundant documentation available for the government plant. This appears to be the only prior attempt to document Armory wartime manufacturing in any detail. Her remarkable use of correspondence makes her work on Armory relations with private firms, manufacturing materials, machine tool developments, and some labor issues the most valuable ever published. She did not deal with factory management, plant expansion, or the importance of minimizing model changes in much detail.

[5] Derwent S Whittlesey, 'A History of the Springfield Armory,' (Ph.D. dissertation, University of Chicago, 1920), chapter 7.

[6] The term rifle-musket refers to muzzle-loaded percussion rifles, as opposed to breech-loaded rifles.

[7] E.g, David J. Williams, *The Birmingham Gun Trade and The American System of Manufactures*, p. 47; Peter Smithurst, 'The Enfield Rifle in America,' *Arms & Armour*, 5, 2 (2008), 178–193.

[8] Ulysses S. Grant recalled that the imported Belgian musket was "..almost as dangerous to the person firing it as to the one aimed at..," in *Personal Memoirs of U.S. Grant*, Vol. I (New York: Library of America, 1990), p. 384.

[9] U.S. Congress, House, 39th Congress, 2nd Session, House Executive Document 54, 1867; ARCO 1862 and 1863, in A Collection of Annual Reports..., Vol. III, pp. 445, 448, 453 and Vol. IV, pp. 844-7, 893-4, 903-4; Robert M. Reilly, *United States Military Small Arms 1816-1865* (Baton Rouge: The Eagle Press, Inc., 1970), pp. 72-5; Russell F. Weigley, *History of the United States Army* (Bloomington, IN: Indiana University Press, 1984), pp. 203, 235-8; Constance M. Green, 'The History of Springfield Armory,' (Springfield, MA: Springfield Armory National Historic Site), Vol. I, pp. 114-33; James M. McPherson, *Battle Cry of Freedom* (New York: Oxford University Press, 1988), pp. 473-6; Philip Katcher, *The Civil War Source Book* (New York: Facts on File, 1992), pp. 57-8. As noted by Fuller, The Rifled Musket, (New York: Bonanza Books,1958), pp. 2-3, older smoothbores included flintlocks converted to percussion and percussion M1842 muskets. Civil War production costs are difficult to compare, but data compiled by Deyrup in *Arms Makers of the Connecticut Valley*, pp. 184-5 and 230, suggest that rifle-muskets made at the Armory cost $12-18 while those made privately cost $18-20. Her estimated costs of over $23 for Armory rifles in 1858 are one indication of the success of wartime manufacture including the effects of greatly increased demand.

[10] Raber, 'Conservative Innovators..', p. 7; David A. Hounshell, *From the American System to Mass Production 1800-1932* (Baltimore: Johns Hopkins University Press, 1984), pp. 46-50; Robert A. Howard, 'Interchangeable Parts Reexamined: The Private Sector of the American Arms Industry on the Eve of the Civil

War,' *Technology and Culture* 19, 4 (1978), pp. 633-649; Donald R. Hoke, *Ingenious Yankees: The Rise of the American System of Manufactures in the Private Sector* (New York: Columbia University Press, 1990); Merritt Roe Smith, 'Yankee Armorers and the Union War Machine,' in *Astride Two Worlds: Technology and the American Civil War*, ed. By Barton C. Hacker (Washington, Smithsonian Institution Scholarly Press, 2016), pp. 25-54.

[11] U.S. Congress, Senate, *Letter from the Secretary of War in relation to the cost of manufactures at the National Armory* (Washington: Government Printing Office, 1879) p. 75; William O. Achtermier, Rhode Island Armsmakers & Gunsmiths, 1643-1883 (Providence, RI: Man at Arms, 1980); Ross Thomson, 'The Continuity of Wartime Innovation: The Civil War Experience.' *Business and Economic History On-Line* 6 (2008). http://www.thebhc.org/publications/BEHonline/2008/thomson.pdf. For detailed summaries of many private contractor histories, see Smith, 'Yankee Armorers,' pp. 36-48.

[12] Raber, 'Conservative Innovators..', p. 10.

[13] [Ordnance] Officers Histories, Vol. 2, RG 156/176.

[14] Whittlesey, p. 222 and Appendix IV.

[15] Michael S. Raber, Patrick M.Malone, Robert B. Gordon, and Carolyn C. Cooper, ed. Richard Colton, *Forge of Innovation: An Industrial History of the Springfield Armory, 1794-1968* (Eastern National, 2008), pp. 111-12, 125.

[16] Letter, Dyer to Ripley, August 21, 1861, RG 156/1354. At least some local citizens, uneasy about the return of military command to the Armory, were probably assuaged by Dyer's retention of Dwight; see *Springfield Daily Republican*, 20 August 1861.

[17] Springfield Armory payroll records, RG 156/1359; Mitchell, p. 205; Deyrup, p. 233. The output figures per worker exclude administrative and other personnel not directly involved in shop management or production, but include foremen and inspectors.

[18] U.S. Congress, House, 37th Congress, 2nd Session, House Report 43; ARCO 1862 and 1863, in *A Collection of Annual Reports...*, Vol. III, pp. 442-3, 453; 'Springfield Armory Post Orders 1861-1874,' nos. 37, 44, 46; Deyrup, pp. 182-3, 233; Mitchell, p. 205. Deyrup's assessment that the Armory lagged behind Ordnance Department quotas (p. 183) is based on an uncharacteristic error; she compared 1862 and 1863 statements of projected calendar year output to actual production reported for fiscal years, which ended June 30.

[19] Colt made revolving pistols and shoulder arms, primarily the former, and no attempt has been made to assess relative productivity. At the height of the war, about 1200 men at Colt's made 300 rifles and 300 pistols daily, for a combined annual output of over 130 pieces per man annually. See figures reproduced in Deyrup, p. 182, and William Hosley, *Colt: The Making of an American Legend* (Amherst, MA: University of Massachusetts Press, 1996), p. 62. Deyrup's collation of comparative data (p. 183) also suggests that Sharps Rifle Company's workers each made an average of some 65 rifles or carbines a year, or about two thirds of Springfield Armory productivity from late 1862 on.

[20] Antebellum Armory costs for land, buildings, and equipment totaled about 1.2 million dollars, compared to some 0.8 million spent during the war; see U.S. Congress, Senate, *Letter from the Secretary of War*, pp. 71-2.

[21] A patchbox designed for the M1861 by Master Armorer Erskine Allin was ultimately omitted, presumably to speed up production as noted by Fuller, The Rifled Musket, p. 17. One of a handful of proposed pattern weapons with this feature is in the SANHS arms collection (SPAR 4419). Precise dating of the first M1861 production is probably impossible with the written records of an increasingly harried Ordnance Department. Dwight to Ripley, June 19, 1861, RG 156/1354, implies that Ripley finally ordered the Maynard primer removed on June 15.

[22] The Model 1864 is sometimes called the Model 1863 Type II. In addition to the three modifications of the Model 1855 made at Springfield, the Ordnance Department approved a Special Model or Colt's Model 1861 which was less interchangeable with the Model 1861. The Colt Company, Lamson, Goodnow, & Yale, and the Amoskeag Manufacturing Company made 152,000 of the Special Model 1861, or about a quarter of the contract rifle-muskets. See Fuller, The Rifled Musket, pp. 11-25, and Eklund and Kellerstedt, 'The Rifle-Musket,' In *Arms for the Nation: Springfield Longarms*, ed. by David C. Clark (Export, PA: Scott A. Duff, 1994)

[23] Thomas K. Tate, *General James Wolfe Ripley, Chief of Ordnance: Answers to His Critics* (Middletown, Delaware: www.booksurge.com, 2008), pp. 15-18, 32; U.S. Congress, Senate, *Letter from the Secretary of War*, p. 75; Stuart C. Mowbray and Jennifer Herouz, eds., *Civil War Arms Makers and Their Contracts* (Lincoln, Rhode Island: Andrew Mowbray Publishers, 1988).

[24] Letters, Ripley to Dyer, March 13, March 28, and June 3, 1862, RG 156/6; Ramsay to Dyer, October 13, 1863, RG 156/13; Dyer to Ramsay, December 28, 1863, RG 156/1354.

[25] E.g., Robert V. Bruce, *Lincoln and the Tools of War* (Indianapolis: Bobbs-Merrill, 1956) , pp. 99-108.

[26] On the plethora of ammunition, see Berkeley R. Lewis, Notes on Ammunition of the American Civil War, 1861-1865 (Washington, DC: The American Ordnance Association, 1959).

[27] Fuller, pp. 1-2; Carl L. Davis, *Arming the Union: Small Arms in the Civil War* (Port Washington, NY: Kennikat Press, 1973).

[28] 16. Bruce is probably the harshest scholarly critic in *Lincoln and the Tools of War*, especially pp. 102-107. William H. Hallahan', more vitreolic attack in *Misfire: The History of How America's Small Arms Have Failed Our Military* (New York: Charles Scribner's Sons, 1994) is based almost entirely on Bruce's work.

[29] Green, p. 101.

[30] Tate, pp. 14, 54-61.

[31] McPherson, *Battle Cry of Freedom*, pp. 474-5; Lewis, *Ammunition*; Tate, pp. 65-9; Joseph G. Bilby, *A Revolution in Arms: A History of the First Repeating Rifles* (Yardley, PA: Westholm Publishing, 2006), pp. 226-7.

[32] Harold F. Williamson, *Winchester, The Gun That Won the West* (Washington: Combat Forces Press, 1952), chapters 2 and 3.

[33] McPherson, p. 275; Tate, pp. 28-9; Patrick M. Malone, e-mail messages to author, April 26, 2016. Hallahan's assertions in Rimfire, pp. 128-5, that a breechloader was worth at least three muzzleloaders seem at best intemperate if one compares range, speed, and reliability. As McPherson and others have concluded, long-range fire had a profound effect on Civil War tactics.

[34] Ibid, p. 203-4; Deyrup, p. 186; Weigley, p. 203; Andrew Lustyik, *Civil War Carbines: From Service to Sentiment*. (Aledo, IL: World-Wide Gun Report, Inc., 1986), p. 22; Norman E. Flayderman, *Flayderman's Guide to Antique American Firearms And Their Values*, 7th Edition (Iola, WI: Krause Publication, 1998) pp. 171-72, 493-506. Hallahan's notion, p. 133, that breechloaders could have been made in Belgium is based on a letter written by Navy Capt. Andrew Harwood of the Ordnance Bureau and quoted by Bruce, p. 106-7. Harwood thought a European factory in a place like Belgium could do the work if provided with a "competent agent" and a pattern weapon. With enough combination of "ifs" we could argue that the English longbow would have sufficed to win the Civil War.

[35] Tate makes a detailed defence of Ripley.

[36] Letters, Dyer to Ripley, September 19, 1861, October 12 and 24, 1861, RG 156/1351; Dyer to Ramsay June 18, 1864, RG 156/1354; *Springfield Daily Republican* 12 August 1861; ARSA 1862, 1863; Prescott, 'The United States Armory.'

[37] Dwight to Ripley, June 17 and July 20, 1861, RG 156/21; *Springfield Daily Republican* July 12, 1861; Dyer to Ripley, March 8, 1862, RG 156/1354.

[38] Dyer to Ramsay, May 30, June 11, and June 23, 1864, RG 156/1354; ARSA 1862, ARSA 1863; Shedd and Edson, 'Topographical Plan of the Springfield Armory, Springfield, Mass. April 1864,' SANHS.

[39] 'Springfield Armory Post Orders,' no. 20 (April 5, 1862).

[40] Dyer to Ramsay, June 21, July 3, and July 4, July 18, and July 30, 1864, RG 156/1354; 'Springfield Armory Post Orders,' no. 12 (December 22, 1861).

[41] Deyrup, pp. 180-2, 194-6; Dyer to Ripley, March 6, 1862, RG 156/1354.

[42] Dyer to Ramsay, October 22, 1863, RG 156/1354.

[43] Chafee to Laidley, September 26, 1865, RG 156/1365.

[44] Deyrup, p. 193.

[45] Dyer to Ripley, August 29, 1862, RG 156/1354; Deyrup, pp. 189-92; Allan Nevins, *Abram S. Hewitt, with Some Account of Peter Cooper* (New York: Harper & Brothers, 1935), pp. 193-99, 206-14.

[46] Dwight to Ripley, June 13, 1861, RG 156/21.

[47] Microfilmed Springfield Armory Records, Miscellaneous Volumes, Microfilm Reel #233, SANHS.

[48] Dyer to Ramsay, February 4, 1864, reproduced in *A Collection of Annual Reports*..., Vol. IV, pp. 860-77.

[49] The 1851 list, compiled by Robert B. Gordon from *Bessey's Springfield Directory* for 1851-2, appears in Raber *et al*., *Forge of Innovation*, p. 223.

[50] Springfield Armory Payroll Records, RG 156/1379.

[51] Charles H. Fitch, *Report on the Manufactures of Interchangeable Mechanism* (Tenth Census of the United States, 1880), pp. 20-21.

[52] Fitch, pp. 27-8.

[53] Prescott, pp. 445-6.

[54] The preceding five paragraphs are adapted from material prepared by Robert Gordon, in Raber *et al*., *Forge of Innovation*, p. 227-8.

[55] Fitch, p. 631; Nathan Rosenberg, ed., *The American System of Manufactures* (Edinburgh: Edinburgh University Press, 1969), pp. 181, 191; Carolyn C. Cooper, 'A Whole Battalion of Stockers: Thomas Blanchard's Production Line and Hand Labor at Springfield Armory' *IA The Journal of the Society for Industrial Archeology* 14 (1988): 37-57.

[56] Raber et al, Forge of Innovation, p. 229.

[57] Armory inventory for 1 July 1872.

[58] See note 46 above.

[59] Besides the Ames Manufacturing Company of Chicopee, which had a long-standing relationship with the Armory and had made the stocking machines for Enfield Armoury in England, potential Civil War makers of stocking machines included any makers of Blanchard lathes for other purposes, such as the hat-block machines of Gilman and Townsend in Springfield, Vermont.

[60] See note 47 above.

[61] Letters, Dyer to Thomas Russell, August 27, 1861, RG 156/1351; Dyer to Ripley, January 15, 1862, RG 156/1354; 'Springfield Armory Post Orders,' no. 13 (October 13, 1862); Deyrup 197-99.

[62] The *Springfield Daily Republican* carried advertisements from many private contractors during the war, but none from Springfield Armory. The paper's edition of August 12, 1861 reported that about fifty men a day were applying for Armory jobs. In February 1862, Dyer had to control the apparent surge of applicants by restricting their entry on Armory grounds to a 45-minute period in the late afternoon ('Springfield Armory Post Orders,' no. 16 (February 1, 1862).

[63] U.S. Congress, Senate, *Annual Report of the Secretary of War*, 1861, p. 7.

[64] Dwight to Ripley, May 4, 1861, RG 156/1354.

[65] *Springfield Daily Republican*, July 12, 1861.

[66] 'Springfield Armory Post Orders,' nos. 3, 63, and 71 (September 31, 1861, July 23 and September 29, 1864). Although the first order does not mention Sundays, the latter two are evidence of Sunday work.

[67] Deyrup, p. 200. We have not been able to locate original documentation for the initiation of extra night pay.

[68] Deyrup, Appendix D, tables 3 (pp. 241-3) and 7 (p. 249).

[69] Whittlesey, Chapter 5.

[70] Deyrup, pp. 200-201. There have been no attempts made to assess the extent of Armory worker turnover during the war.

[71] Michael H. Frisch, *Town into City: Springfield, Massachusetts, and the Meaning of Community, 1840-1880*. (Cambridge: Harvard University Press, 1972), ch. 4.

[72] *Springfield Daily Republican*, April 8, 1862.

[73] Dyer to Ripley, various letters from November 8, 1861 to March 20, 1863, and Dyer to Ramsay, various letters from October 3, 1863 to August 29, 1864, RG 156/1354.

[74] Dyer to Ripley, July 27, 1863, RG 156/1354. There were no occupational exemptions. Actual Armory employment rose through the tense period of the first draft call, however, suggesting that some workers paid the $300 commutation fee and others were replaced by eager new hires. On the draft, see McPherson, *Battle Cry of Freedom*, pp. 600-606.

[75] 'Springfield Armory Post Orders,' nos. 24, 26, 30 (July 8, September 8, and November 24, 1862); Deyrup, p. 200.

[76] Deyrup, p. 197.

[77] 'Springfield Armory Post Orders,' nos. 11 and 44 (November 21, 1861 and July 3, 1863; Springfield Armory Payroll Records. Problems with barrel quality persisted, and evidently increased, throughout the war. Whether because of raw material or workmanship, barrel rejection rates rose from about 8 percent in mid-1863 to 15-20 percent throughout 1864; see RG 156/1385.

[78] Deyrup, p. 201.

[79] The Learner job category was not recognized in 'Springfield Armory Post Orders' until July 23, 1864 (No. 63), but was probably established earlier. Deyrup, p. 200, noted that the $1.25 paid per day was considered a good pre-war wage.

[80] Springfield Armory Payroll Records, May 1859, January 1860, January 1864.

[81] Deyrup, p. 201, noted that "..the war awakened the Springfield Armory to something like a modern understanding of plant efficiency," but devoted little attention to the issue.

[82] Alfred Chandler wrote that "[m]odern factory management… had its genesis in the United States in the Springfield Armory," in *The Visible Hand: The Managerial Revolution in American Business*. (Cambridge: Harvard University Press, 1977), p. 75.

[83] Capt. Henry Metcalfe, *The Cost of Manufactures and the Administration of Workshops, Public and Private*, (3rd ed., New York: John Wiley & Sons, 1907), p. 8.

[84] Whittlesey, chapter 7; Michael S. Raber *et al.*, 'Conservative Innovators and Military Small Arms,' p. 200. An oath of allegiance, required of all officers and employees in 1862 by the Adjutant General of the Army, probably had little effect on Armory management; see 'Springfield Armory Post Orders,' no. 25 (August 16, 1862).

[85] 'Springfield Armory Post Orders,' nos. 2, 26, and 61 (September 1, 1861, September 8, 1862, and May 31, 1864).

[86] 'Springfield Armory Post Orders,' nos. 2, 8, and 11 (September 1, October 31, and November 21, 1861).

[87] Ibid, nos. 14, 19-21, 33, and 41 (January 15, March 26, April 5 and 30, and December 6, 1862; June 5, 1863).

[88] Ibid, no. 46 (September 7, 1863).

[89] Ibid, no. 61 (May 31, 1864).

[90] [Ordnance] Officers' Histories, Vol. 1, RG 156/177; Metcalfe, *The Cost of Manufactures*, pp. 18-20, 33, and 'The Shop-Order System of Accounts' *Transactions of the American Society of Mechanical Engineers* VII (1886), pp. 440-488; Alfred D. Chandler, Jr., *The Visible Hand*, pp. 269-75. Metcalfe's use of coded punch-outs on his shop-order tickets allowed for later sorting by cost category, and was a precursor of automated data analysis on early computers.

[91] Metcalfe, Cost of Manufactures, pp. 59-61.

[92] For an extended exposition of this view, see David A. Hounshell, From the American System to Mass Production, especially Introduction, and Michael Best, *The New Competition: Institutions of Industrial Restructuring* (Cambridge: Harvard University Press, 1993), pp. 51-2.

[93] Chandler, The Visible Hand, p. 241. Best's use of Chandler's definition while denying that Armory practice ever reached the level of mass production, in *The New Competition*, suggests he was unaware of Springfield's wartime performance.

[94] Smith, 'Yankee Armorers,' with telling comparison of Armory and Ford Motor Company output, p. 35.

[95] Military magazine rifle development and selection was also hindered by officers' fears of wasting ammunition, and cartridge issues in fouling repeating rifle mechanisms which were not fully resolved until the American adoption of smokeless-powder brass cartridges in the late 1880s. Raber et al, *Forge of Innovation*, pp. 269-72; Patrick M. Malone, e-mail messages to author, April 26, 2016.

Notes on Contributor

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