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KEN ALDER

At the Hôtel des Invalides on November 20, 1790, a gunsmith-inventor named Honoré Blanc stunned French academicians, politicians, and military men. Under the sponsorship of the artillery service, Blanc had manufactured some one thousand gunlocks at an experimental workshop in the Vincennes dungeon, just outside Paris. Now, in front of these august dignitaries, he demonstrated the interchangeability of their parts. Selecting pieces from bins, Blanc reassembled several functional gunlocks. This publicity stunt coincided with his pamphlet to the new National Assembly, proposing a centralized state-run workshop that would run to the rhythm of uniform production. Such a workshop would sweep away the "ancien régime of the manufactures" and satisfy all of France's need for muskets. It would lower the price of making and repairing guns and prompt further innovations from a new breed of machine-tool makers. It would also provide work for the unskilled vagabonds who troubled the countryside.[1]

Historians of technology have long been aware that the method of interchangeable parts manufacturing originated in 18th-century France—and of the role played by Thomas Jefferson in bringing word of this method to the United States. Forty years ago, Robert Woodbury called attention to Jefferson's letter to John Jay of August

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[1] Honoré Blanc, *Mémoire important sur les fabrications des armes de guerre* (Paris, 1790).

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30, 1785, which reported on the demonstration Jefferson had witnessed in Blanc's workshop.[2] Since Woodbury's time, Edwin Battison, Merritt Roe Smith, and David Hounshell have told the subsequent history of interchangeable parts manufacturing in the United States: the tentative efforts of Eli Whitney, the technical achievements of the American armories, the practical successes of the private New England gun factories, the adaptations of the sewing machine and bicycle makers, and ultimately, the triumph of the assembly-line methods of Henry Ford.[3] This history, we have been told, addresses one of the "big questions" in the history of technology for two reasons: because of its centrality to the development of mass production, itself the ideal form of rational production, and, paradoxically, because it constituted a specifically American style of production.[4]

But the French story of the invention of interchangeability has gone largely untold, and this silence is revealing both of our persistent assumptions about the nature of technological change and of our reliance on the official guardians of technological memory.[5] When, in the 1850s, English investigators brought word back to Europe of the "American system of manufacturing," they found that the French military had never heard of the method—let alone of Honoré Blanc.[6] Hence, historians too have never felt any need to investigate further. But this strange technological amnesia should

[2]Jefferson to John Jay, August 30, 1785, *The Papers of Thomas Jefferson*, ed. Julian P. Boyd (Princeton, 1950–), 8: 452–56. Robert S. Woodbury, "The Legend of Eli Whitney and Interchangeable Parts," *Technology and Culture* 1 (1959): 235–53.

[3]Edwin A. Battison, "Eli Whitney and the Milling Machine," *The Smithsonian Journal of History* 1 (1966): 9–34. Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca, 1979). David Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Baltimore, 1983). See also Carolyn C. Cooper, Robert B. Gordon, Patrick M. Malone, and Michael Raber, *Model Establishment: A History of the Springfield Armory 1794–1918* (forthcoming).

[4]George Daniels, "The Big Questions in the History of American Technology," *Technology and Culture* 11 (1960): 1–35.

[5]Selma Thomas briefly highlighted Blanc's achievement in " 'La plus grande économie et la précision la plus exacte,' L'oeuvre d'Honoré Blanc," *Bulletin trimestriel des Amis du Musée d'Armes de Liège* 7 (1979): 1–4. See also W. F. Durfee, "The First Systematic Attempt at Interchangeability in Firearms," *Cassier's Magazine* (April 1894): 469–77; and John E. Sawyer, "The Social Basis of the American System of Manufacturing," *Journal of Economic History* 14 (1954): 361–79.

[6]Nathan Rosenberg, ed., *The American System of Manufactures* (Edinburgh, 1969); see especially the editor's introduction. For attempts to alert the French to these methods, see S.H.A.T. 4f8/1 Kreutzberger, "Rapport addressé à M. le Président de la Comité d'Artillerie," 1856.

pique our curiosity, not dampen it. Such a trajectory of success and failure violates our most common understanding of technological progress: that there is a self-evident direction of industrial development, a logic by which production necessarily becomes ever more "rational." Charles Sabel and Jonathan Zeitlin have, in a well-known article, criticized economic historians who assume that production tends inevitably toward the Fordist ideal. They point out that this teleological narrative obscures the history of alternative forms of industrialization, such as flexible specialization, the technique by which small firms adapt their machinery in response to a changing market. With their admonition in mind it is now time, as Yves Cohen has suggested, to tell a nonteleological history of "mass production." Doing so will suggest how a focus on "big questions" can blind us to the shifting nature of "rationality" as it is realized in methods of production.[7]

Certainly, interchangeable parts manufacturing is a key element of modern mass production. Yet it better expresses an ideal than describes the methods of achieving that ideal, or why it is worth pursuing in the first place. Interchangeability is a sign that the parts of an artifact have been made so precisely that they can be assembled without a final "fitting." In their humble way, Blanc's methods achieved this ideal. Blanc relied on steel dies to drop forge pieces with precision, filing jigs and hollow milling machines to shape them accurately, and an elaborate set of gauges to verify that finished pieces fell within requisite tolerances. Although many of his procedures still relied on hand tools and human muscle, execution (in principle, anyway) depended on mechanical guides. Each worker was now obliged to produce pieces to the requisite tolerance so that they would fit together in the final assembly. In this sense, the production process itself acted as an intrinsic check on the proper conduct and workmanship of the artisan. And the "fit" of the artifact was a measure of the rigor with which the social order was policed.

But this is not to equate Honoré Blanc's Vincennes machine shop with Henry Ford's Highland Park plant. To achieve mass produc-

[7]Charles Sabel and Jonathan Zeitlin, "Historical Alternatives to Mass Production: Politics, Markets and Technology in Nineteenth-Century Industrialization," *Past and Present* 108 (1986): 133–76. Yves Cohen, "Inventivité organisationnelle et compétitivité: L'interchangeabilité des pièces face à la crise de la machine-outil en France autour de 1900," *Entreprises et histoire* 5 (1994): 53–72. For a warning against describing 18th-century developments with 20th-century terms such as "mass" production and "mass" consumption, see John Styles, "Manufacture, Consumption, and Design in Eighteenth-Century England," in *Consumption and the World of Goods*, ed. John Brewer and Roy Porter (London, 1993), pp. 527–52.

tion, Ford combined a factory setting, a relentless division of labor, and cradle-to-grave mechanization. In his scheme, interchangeability of parts allowed low-skill wage laborers to assemble a prodigious number of Model Ts at low unit costs. Not only were Ford's methods of mass production different; so too were the sort of labor he used, the market he cultivated, and the ends he pursued. Under Fordism, interchangeability was driven by the hunger for a return on capital.[8]

But the end result should not be mistaken for the cause. The 18th-century French effort to make things identical was part of a larger Enlightenment project to replace the corporate order with a more innovative technological regime. This was not, however, a proto-Fordist scheme driven by capitalist entrepreneurs seeking profit, but rather an engineering program driven by state bureaucrats following their own operational logic. To be sure, theirs was a failed industrial revolution. Yet even failures can be consequential and illuminating. Consequential, because even failed techniques may come to find successful application; the engineering approach to production, once it was subordinated to capitalist organization in the late 19th century, had a transformative effect on industrial practice. Illuminating, because tracking the success and failure of this engineering program will uncover a past which operated by a rationality different from our own. It will thereby help us to understand the pattern of modern capitalist industrialization as it *did* emerge in the wake of the French Revolution. The result will be to show how the artifacts produced by these techniques—artifacts such as guns—are not the material residue of an inexorable logic of technological development, but the negotiated outcome of political struggle.

Military Production and the Killing System

Various scholars have highlighted the contribution of European military competition to early industrialization. Sombart noted that the early modern state was a ready source of capital for new technologies, and Mumford argued that the army offered a unique mass market for relatively cheap and undifferentiated products. But the military market was also erratic, rising and falling with the fortunes of war and peace. As a rule, therefore, the states of early modern Europe did not directly own the means of military production.[9] They let merchants and local producers—"capitalists" of one sort or an-

[8] Lindy Biggs, *The Rational Factory: Architecture, Technology and Work in America's Age of Mass Production* (Baltimore, 1996).

[9] Werner Sombart, *Krieg und Kapitalismus* (New York, 1975), pp. 74–116. Lewis Mumford, *Technics and Civilization* (New York, 1934), pp. 89–98. Charles Tilly, *Coercion, Capital, and European States, A.D. 990–1992*, rev. ed. (Cambridge, Mass., 1992).

other—absorb the risks and reap the profits of these investments, and in return they cloaked these intermediaries in legal privileges. They also sent emissaries to make sure that these merchants and producers delivered goods for a reasonable price and with some assurance of quality.

Since the beginning of the 18th century, the artillery service had been the sole intermediary through which the French state acquired its weaponry. Trained in the first schools in Europe to offer systematic scientific instruction, these engineers acquired skills in mathematics, rational mechanics, technical drawing, and practical administration. They were highly trained professionals who vied in meritocratic competition and whose highest ethos was state service. They also supervised a vast assemblage of private cannon foundries and musket manufactures, plus a smattering of state-owned workshops. Their efforts to transform production in this proto-military-industrial complex were intrinsic to their effort to field an effective "killing system" for battle.

Blanc's efforts to produce interchangeable gunlocks was part of a larger program by these military engineers to improve the effectiveness of the French army after the humiliations of the Seven Years' War. Beginning in 1763 the artillery service undertook a series of radical reforms under the leadership of Inspector General Jean-Baptiste de Gribeauval. They redesigned the French cannon and their mode of use, forging men, machines, and tactics into a coherent system. These cannon operated in conjunction with the controversial new "mixed" tactics of Jacques-Antoine-Hippolyte de Guibert, which deployed a thin line of infantry to maximize the firepower of muskets.[10] Yet even the partisans of these new tactics admitted that the current small arms themselves were woefully inadequate. One artillerist, Tronson Du Coudray, calculated their kill rate as no better than one shot in 150, whereas the new Gribeauvalist cannon killed eleven times as many. Du Coudray urged his countrymen to "perfect your muskets as you have begun to perfect your artillery."[11] Thus in

[10] Jacques-Antoine-Hippolyte de Guibert, *Essai général de tactique* (London, 1772). See also Ken Alder, *Engineering the Revolution: Arms and Enlightenment in France, 1763–1815* (Princeton, 1997), pp. 23–124.

[11] [Philippe-Charles-Jean-Baptiste Tronson Du Coudray], *L'ordre profond et l'ordre mince, considérés par rapport aux effets de l'artillerie* (Metz, 1776), p. 92 (translations from French are the author's throughout). One might say that within the army's "killing system," the musket represented a "critical problem" that attracted attention from military system builders. Thomas P. Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch (Cambridge, Mass., 1987), pp. 51–82.

the late 1770s the Gribeauvalists turned their attention from cannon to muskets. The M1763 musket, designed by the Gribeauvalists, had been scorned by troops who found it too heavy, and it had been modified in 1766, 1768, 1770, and 1774. Despite the official obligation to buy identical weapons from the artillery service, colonels routinely custom-ordered muskets for their troops, and troops in the field were notorious for personalizing their firearms. Hence, Gribeauval's 1777 redesign of the musket was also intended to reassert the service's authority as the sole supplier of armaments. In this context, "uniform production" meant artillery control.

In 1777, the Gribeauvalists returned to power after a two-year hiatus occasioned by their controversial reforms. With the controversy over thin-line tactics still raging, they announced a new musket design. To ensure the gun would be of superior quality—and accepted as such—they held an "open" competition. The winning design was the one proposed by an armorer named Honoré Blanc at a state-supported workshop.[12] Blanc bragged that only with the M1777 musket "had anyone seriously concerned himself with perfecting the firearm since every piece, without exception, has been thought about and discussed, and whenever there remained the least uncertainty, we had recourse to experiment."[13] The implication was that nothing had been left to chance or tradition, that every aspect of the gun had been reviewed in purely instrumental terms, as a component in the army's new tactics.[14]

We should not, however, exaggerate this disjuncture. Between 1700 and 1840, the design of the flintlock musket remained essentially static. Within this basic smoothbore design, therefore, the Gribeauvalists' main effort was directed toward procuring a more effective musket by producing a more precise one.[15] To this end the artillery engineers sought to create and enforce a set of rigorous standards, hoping to "normalize" the performance of the weapon and thus make it more reliable, accurate, and deadly. They did so by applying to the commercial world of production the same systems

[12]S.H.A.T. 4f22/1 Gribeauval, Montbarey, Du Châtelet, [No title], January 24–February 7, 1776. S.H.A.T. 4f3 Blanc, "Etat de dépenses," March 18, 1777.

[13]S.H.A.T. MR1741 Honoré Blanc, "Mémoire historique sur les progrès," April 27, 1777.

[14]Jean Boudriot, "L'évolution de la platine de l'arme d'infantrie française," *Gazette des armes* 68 (1979): 35. Artillery professor Lombard later suggested how to maximize the performance of the M1777 in conjunction with Guibert's tactics. Jean-Louis Lombard, *Traité du mouvement des projectiles* (Dijon, year V [1796–97]), pp. 186–201.

[15]Maurice Bottet, *Monographies de l'arme blanche (1789–1870) et de l'arme à feu portative (1718–1900) des armées françaises de terre et de mer* (Paris, 1959), pp. 135–62.

approach they had so successfully imposed on the operation of soldiers and weapons in battle.

Scholars have long argued that military operations offered a model for managing complex activities, including productive labor. As Max Weber put it, "military discipline is the ideal model for the modern capitalist factory." Recently David Noble has expanded on this insight, citing the military ideal of command and control as a template for the proletarianization of industrial labor. But the military model of management was not easily transferred to the world of commercial relations. Making that translation proved to be a protracted struggle, one which provides valuable insight into the (difficult) transition from the putting out system to industrial production.[16]

The Instruments of Practical Reason

Why did the engineers turn to the uniformity system of production? Or to put the question in historicist terms: how did the uniformity system emerge from an 18th-century contest over how the productive life should be organized? Many elite thinkers of the time were convinced that artisanal production was deficient. French savants associated with the Physiocratic movement launched a concerted attack on the artisanal guilds (called "corporations"), and one of the Physiocrats' adherents, Chief Minister Turgot, abolished the guilds (temporarily) in 1776. But for all their hostility to the guilds, these elites recognized that the corporations organized the social life of artisans and daily practices in the workplace. They were looking for alternatives, yet they did not necessarily anticipate the outcomes that today leap to the historian's lips: "the entrepreneur," "the machine," "the market." What they sought was a way to bring theoretical knowledge to bear on practical problems. In his famous article "Art" in the *Encyclopédie*, Diderot denounced the secret and collusive craft knowledge of the guilds for stifling innovation and blocking access to the trades. Instead, he called for an open public discussion of technology.[17] The French engineers took up this challenge, offering novel techniques for drawing artifacts on paper and for defining them with physical tools and machines. Implicit in these new representations was a new conception of work, and a new vision

[16]Max Weber, *Economy and Society: An Outline of Interpretive Sociology* (Berkeley, 1968), 2: 1155–56. David Noble, "Command Performance: A Perspective on the Social and Economic Consequences of Military Enterprise," in *Military Enterprise and Technological Change*, ed. Merritt Roe Smith (Cambridge, Mass., 1985), pp. 329–46.

[17]Diderot, "Art," *Encyclopédie* (Paris, 1751), 1: 716.

of the productive order. By the end of the 18th century they had introduced interchangeable parts production. Why?

One way to answer this question is to rattle off those timeless qualities of rationality—precision, uniformity, control, efficiency—to which engineers are "innately" committed. Or one might point to aesthetic principles fostered by the Enlightenment. Certainly, the ideals of harmony and regularity had considerable appeal to Enlightenment engineers. In 1750, Colonel Claude-Marie-Valenninet Le Duc—a close collaborator of Gribeauval—advocated the standardization of artillery carriages, because to the rational, well-ordered mind, the absence of uniformity was a "dismal cacophony."[18] But this aesthetic had long appealed to military men without resulting in any practical reforms. Moreover, this approach risks reintroducing idealism and teleology through the back door. The central tenet of this article is that (engineering) rationality is not a set of timeless abstractions but a set of social practices which have emerged historically. Rational production is a prime example of this. If we consider how engineers enacted shibboleths such as control, efficiency, or uniformity in practice, we begin to see how a given form of production emerged as a particular solution to a particular set of historical problems.

Take, for instance, the various practical means by which interchangeable parts production is usually said to have been achieved. In Woodbury's article on Eli Whitney, he cites four "instruments" as prerequisites for interchangeable parts production: precision machine tools, precision gauging, uniformly accepted standards of measurement, and techniques of mechanical drawing.[19] This formulation properly emphasizes the role of standards in realizing interchangeable parts production. But Woodbury's list still reads like a set of preordained criteria. As we will see, the French engineers developed these four instruments because they lacked the one factor Woodbury takes for granted; they had no direct control over the process of production. They approached production as an exchange: in return for the king's coin they wanted guns of a well-defined sort.

In such a situation, the instruments of production emerge not as the willful imposition of rational planners upon irrational makers but as the outcome of a process of conflict and negotiation over

[18]Le Duc, "Mémoire concernant la connaissance, le détail et l'usage des principaux attirails de l'artillerie," 1750, cited in Howard Rosen, "The Système Gribeauval: A Study of Technological Development and Institutional Change in Eighteenth-century France," (Ph.D. diss., University of Chicago, 1981), pp. 135–37.

[19]Woodbury, "Eli Whitney" (n. 2 above).

the terms of an exchange. Inspectors' demands for adherence to stringent standards (especially when backed by the state's unique powers of enforcement) stir resentment among producers and merchants, who fear that they will bear the costs of meeting those standards. And when these producers and merchants attempt to cut corners, inspectors try to make the standards more difficult to circumvent, which typically means making them as rule-bound as possible, often by embedding them in physical devices. Hence, the development of the instruments that mediate the exchange—drawing, gauges, machinery—is the outcome, not the precondition, of conflict in the workplace—though such seeming resolutions are always occasions for further conflict and renegotiation. The history of these tools, then, charts the changing relations of production in that society. To the extent that an artifact (here, a gun) is the sum of its standards of production, its qualities reflect the changing nature of those relations.[20]

Such a formulation presents several advantages. First, rather than assume that struggle in the workplace begins with conflict over the use of tools and machines (as do most Luddite-inspired accounts), it folds the development of these instruments back into the larger history of production. Second, by historicizing the development of those instruments, it reminds us that they do not define a unique organization for production. Indeed, other ways of organizing production, such as flexible specialization, were then current in France, and they too invoked standards as a way to coordinate production. And finally, it does not prejudge the relative strength of the various parties involved in production. It reminds us that engineers and managers do not always succeed in imposing their vision of production upon artisans and laborers. Obviously, significant power disparities do exist between inspector-engineers and worker-producers. In the extreme case of monopoly capitalism, workers may be wholly without alternatives or resources, and managers may have an almost unrestricted ability to impose their standards. In other cases—if, for instance, the inspectors are state engineers and the producers are autonomous artisans—workers may, under the right market conditions or with the right sorts of social solidarities, dictate terms to the engineers and the central state. The point may well be a general one. Similar patterns of mistrust and conflict obtain wherever managers address themselves to production.[21]

[20] For a suggestive hint along these lines, see Steve Lubar, "Representation and Power," *Technology and Culture* 36 (1995): S54–S81.

[21] Michael Buroway, *Manufacturing Consent: Changes in the Labor Process under Monopoly Capitalism* (Chicago, 1979), pp. 5–56.

For the 18th-century theoreticians of the workplace, one of the principal instruments for mediating these exchanges was technical drawing—what Diderot called "the geometry of the workshop."[22] Technical drawing promised to organize the workshop on both procedural and social levels. First, by distinguishing between the conception of an artifact and its execution, technical drawing suggested how one might redistribute tasks within the workshop and provide a standard for production. And second, by creating a common language for both artisans and engineers, it bound and ranked the members of the productive order. As a quasi-public and mathematicized language, mechanical drawing is what Bruno Latour calls an "immutable mobile," or what Theodore Porter calls a "technology of distance." Here "distance" has at least three layers of meaning. First, mechanical drawing bridges the epistemological mistrust that exists between the inner eye and the external world by reducing the representation of objects to a set of formal and invariable rules. In this sense, a mechanical drawing is an "objective" picture of an artifact, even though it "looks" nothing like the artifact. Second, mechanical drawing thereby allows for a common conception of an artifact across space and time, particularly useful for bureaucracies which coordinate far-flung activities. And third, mechanical drawing helps bridge the chasm of mistrust that lies between workplace groups by providing them with a common referent—even as it subordinates those who carry out the drawings' instructions to those who conceive them.[23] New projective forms of mechanical drawing—still in use today—were developed by the 18th-century French engineers to serve all these roles. And the Gribeauvalists produced elaborate plans of all their new matériel.[24]

Mental representations are essential to the organization of work, but pictures do not, in and of themselves, discipline artifacts or coerce labor. So to translate their drawings into artifacts, engineers embodied their instructions in physical instruments, such as gauges, jigs, cutters, fixtures, dies, and machinery. These devices are the foundation of both interchangeable parts manufacturing and flexible specialization because they transform the general action of a hu-

[22]Diderot (n. 17 above).

[23]Bruno Latour, "Drawing Things Together," in *Representations in Scientific Practice*, ed. Michael Lynch and Steve Woolgar (Cambridge, Mass., 1990), pp. 20–69. Theodore Porter, *Trust in Numbers: Objectivity in Science and Public Life* (Princeton, 1995).

[24]Jean-Baptiste Vaquette de Gribeauval, *Tables de construction des principaux attirails de l'artillerie proposées ou approuvées depuis 1764 jusqu'en 1789*, ed. Jacques Charles Mason (Paris, 1792). For further information on the development of engineering drawing in the Enlightenment, see Alder, *Engineering the Revolution* (n. 10 above), pp. 136–46.

man hand or machine into a specific action. Some scholars have seen these devices as disciplinary tools which de-skill workers, and hence, agents of proletarianization. But as Robert Gordon has pointed out, gauges, jigs, and fixtures put heavy demands on the skills of metalworkers well into the 19th century.[25] To be sure, gauges reduced the latitude of workers by setting standards for acceptable pieces. And jigs and fixtures limited the discretion of workers whose tools were now guided. But there is no a priori reason why a metalworker might not set up the jigs and fixtures on his or her own machine. Then, too, enormous skill goes into the making of these gauges, jigs, and cutters, and these might be made by the same worker who tended the machine. Throughout the 18th century, there was ongoing conflict over the use of these devices. That is because gauges and jigs define the limits of the agreement between the parties involved in production. In this sense, they are the physical bearers of manufacturing "tolerance," a term first introduced by the artillery engineers of ancien régime France.[26]

Manufacturing tolerance, despite the connotations of the word "tolerance," actually increases the stringency of the supervisor's control over the work process by explicitly spelling out the limits of acceptability. Gauges are "objective" measures of artifacts, then, in the sense that they appear to bind workers and inspectors to a common set of impersonal rules at just those points where the possibilities for conflict are greatest. This form of objectivity is akin to that described by Theodore Porter, in which the prevalence of quantification in public life is a sign of past conflict.[27] This seeming "objectivity" does not mean that all conflict comes to an end, however.

Consider the analogous discussion by E. P. Thompson of the transition from task-time to clock-time in early modern manufactures. This was a protracted struggle in which wage-earners gradually lost much of their ability to control the work process. Once workers are obliged to labor by clock-time, however, if six o'clock is quitting time, then when the clock says six it's time to quit. And if a worker doesn't trust the foreman's clock, he or she can check the time on a pocket watch. Moreover, the worker can now frame an argument about the number of hours he or she will work.[28] Similarly, gauges

[25] Robert B. Gordon, "Who Turned the Mechanical Ideal into Reality?" *Technology and Culture* 29 (1988): 744–78.

[26] Historians have usually located the earliest use of tolerance in the mid-19th century; see Peter Geoffrey Booker, *A History of Engineering Drawing* (London, 1979), pp. 187–89.

[27] Porter, *Trust in Numbers.*

[28] E. P. Thompson, "Time, Work-Discipline, and Industrial Capitalism," *Past and Present* 38 (1967): 56–97. The same pattern holds true in the transition from customary payment to wage labor, or from the anthropomorphic work-based measures to

and fixtures are something about which workers and inspectors can argue—and for good reason. Tighter tolerances generally demand greater efforts from workers. And who is to say when a piece is finished to gauge? The artifacts of commerce and war are sufficiently irregular that they cannot be completely described. Tolerances can be defined only for a few dimensions. Moreover, because gauging requires "touch," it still leaves considerable room for disagreement. Interchangeable parts production emerged in 18th-century France as an attempt to settle these ongoing disagreements by making judgments about workmanship as impersonal as possible—shifting conflict even further away from individuals and lodging it at the most general level at which production was organized. To see how this occurred, however, one must see how interchangeability emerged out of the colliding interests of artisans, merchants, and engineers. In the rest of this article, I describe the birth of interchangeable parts manufacturing—and its demise—in the armory town of Saint-Etienne.

The Saint-Etienne Armory in the Ancien Régime

The artillery service first achieved interchangeable parts production in the 1760s during its reform of the production of artillery carriages. These wood and metal carriages, which carried cannon into battle, were manufactured at state-owned workshops staffed by worker-soldiers. In carrying out their mandate to centralize the design of these carriages, the artillerists imposed new stringent standards of production, which they embedded in technical drawings and gauges. To their surprise, they also found that the pieces so produced were sufficiently alike to be interchangeable.[29] But when the officers tried to apply these same methods to the production of muskets in the armory town of Saint-Etienne, where the workers were not soldiers but autonomous artisans, they met with a wholly different reception.

In the 19th-century, Saint-Etienne was commonly referred to as the cradle of the French Industrial Revolution because of its large-scale metalworking firms. More recently, Sabel and Zeitlin have described the town as a dynamic industrial district, whose small firms

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the metric system. Peter Linebaugh, *The London Hanged: Crime and Civil Society in the Eighteenth Century* (Cambridge, 1992), pp. 371–401. Ken Alder, "A Revolution to Measure: The Political Economy of the Metric System in France," in *The Values of Precision*, ed. M. Norton Wise (Princeton, 1995), pp. 37–71.

[29] Philippe-Charles-Jean-Baptiste Tronson Du Coudray, *L'artillerie nouvelle ou examen des changements faits dans l'artillerie française depuis 1765* (Amsterdam, 1773), p. 84.

used flexible specialization to adapt quickly to market changes. These somewhat contradictory portraits—with their different implicit social dynamics—make Saint-Etienne a touchstone for how we should conceive the early history of French industrialization.[30] Already in the 18th century, the hundred and twenty thousand inhabitants of the Saint-Etienne basin, just 50 kilometers west of Lyons, were engaged in metalworking, coal mining, and textile production. The artillery engineers known as "inspectors" entered this protoindustrial valley to supervise the artisanal production of muskets.

Their challenge was what might be termed the "problem of command": how to ensure that the guns they bought for the king's troops matched their specifications, not once but ten thousand times. The artillery service purchased military muskets from designated local merchants called *entrepreneurs* (a title, it should be emphasized, and not a description of an actual entrepreneurial role in the current capital-owning sense of that phrase). These *entrepreneurs* subcontracted the work out to artisanal producers. The goal of the inspectors was to shape the relationship between merchants and artisans to get the sort of guns the state wanted in the desired quantity and at the mandated price. To this end, they established new institutions to define standards of production—notably the proof house to test gun barrels and the reception room to inspect gunlocks. And they staffed these inspection sites with expert "controllers" recruited from the artisanal class. But these institutions had to be continually reformulated in the face of resistance by merchants and artisans. And in the end, the engineers were obliged to use legal sanctions to enforce their program. Producing guns which artisans would make, merchants would trade, and engineers would accept meant reformulating the political relationship between the state and its citizen-producers. It is in this sense that the guns of Saint-Etienne were the outcome of political struggle.

At the root of the conflict lay the fact that the division of Saint-Etienne's firearms trade into a civilian and a military sector was a legal fiction rather than an economic fact. In the late 18th century, Saint-Etienne annually produced between forty thousand and sixty thousand muskets destined for various civilian markets in Europe, the Levant, and the African slave trade. At the same time, the town

[30] Michael P. Hanagan, *The Logic of Solidarity: Artisans and Industrial Workers in Three French Towns, 1871–1914* (Urbana, 1980). Sabel and Zeitlin, "Historical Alternatives" (n. 7 above). This debate over Saint-Etienne mirrors a larger debate over the pattern of French industrialization; see Patrick O'Brien and Caglar Keyder, *Economic Growth in Britain and France, 1780–1940: Two Paths to the Twentieth Century* (London, 1978).

annually produced between zero and twenty-five thousand military muskets, depending on the fortunes of war and peace. Both sectors relied on an overlapping group of roughly two thousand armorers, some three hundred to six hundred of whom were signed up for the king's work at any one time.[31] The separation of the two sectors rested on an oft-reiterated 17th-century law stipulating that only designated merchants could contract with designated armorers to make guns of military caliber (defined as a bore that would take balls weighing eighteen to the pound). However, since military armorers could still work for the private market, and merchants holding military contracts could sell nonmilitary guns privately, inspectors had to cope with an endless quasi-legal traffic in personnel, raw materials, and finished and half-finished goods. Enforcing standards of production enabled the engineers to police the boundary between these two types of guns—and these two political-economic worlds.

Both sectors also depended on the services of arms merchants. The civilian market was coordinated by a shifting population of some one or two hundred arms merchants, who ranged greatly in fortune. Of these, some eight to ten large-scale merchants known as *négociants* vied for contracts to supply armaments to the king. In 1769, with the backing of Gribeauvalists, the leading figure in one of these families, Carrier de Monthieu, won the monopoly privilege of constituting himself the sole *entrepreneur* of the "Royal Manufacture of Arms." But even then there was no armaments factory, there were only a few administrative buildings, and 90 percent of military armorers still worked in their own shops and sold their products for a negotiated price—just as they did in the private market. In the two other French armories, Charleville and Maubeuge on the northern frontier, a single *entrepreneur* had long ago collected his gunsmiths under a common roof. But Saint-Etienne resembled its rival arms-making towns, such as Birmingham and Liège, with their dispersed craftsmen-proprietors.[32]

To the schooled artillerists and state officialdom, the life of a Saint-Etienne artisan seemed alien—its dialect foreign, its motives

[31] Paul Maguin, *Les armes de Saint-Etienne* (Saint-Etienne, 1990), p. 51. Jean-Marie Roland de la Platière, *Manufactures, arts et métiers*, vol. 2, pt. 2, Encyclopédie méthodique (Paris, 1790), pp. 46–48. Louis-Joseph Gras, *Histoire de l'armurerie stéphanoise* (Saint-Etienne, 1905), p. 100.

[32] A.N. F12 1309 "Mémoire: réponse des négociants aux objections des Entrepreneurs," [1765]. Maguin, *Armes*, p. 48. S.H.A.T. 4f5 Danzel de Rouvroy, "Etat et dénombrement général des ouvriers," January 1, 1782. François Bonnefoy, *Les armes de guerre portatives en France du début du règne de Louis XIV à la veille de la Révolution (1660–1789): De l'indépendance à la primauté* (Paris, 1991), pp. 237–68.

venal, collusive, and base. In contrast to the engineers' plodding progress up a career hierarchy, the artisan's life ran to various interwoven rhythms—the task-time of gunmaking, the cycle of festival seasons, and the lifetime itinerary from apprenticeship to journeyman to master— all overlaid by the irregular fluctuations of market prices and military orders. If anyone was an "entrepreneur" in the ancien régime, it was these petty commodity producers. They owned their own shops, bought raw materials, hired a journeyman or two, and sold their goods in full risk of market downturns. Many, such as Honoré Blanc, Joseph Bonnand, August Merley, and Jean-Baptiste Javelle, innovated within their craft. They experimented with "ribbon-wound" gun barrels, multiple-shot muskets, and damask and engraved decorations. All master artisans made their own tools. Some, such as Javelle and Blanc, invented special-purpose machine tools.[33]

Most of Saint-Etienne's armorers did not reside in the town proper but were scattered across the valley in patterns that reflected the division of labor in the trade. Already in the 18th century, a firearm was the joint product of some two dozen subtrades. Across the generations, members of the same family plied the same arms-making subspecialty. No formal avenues of instruction were available. Training was by apprenticeship, usually with older male relatives. These skills could not be easily acquired and belonged to a form of bodily, tacit knowledge that could not be exhaustively described.[34]

In the view of the engineer-artillerists, however, the armorers were "the most thick-skulled workers imaginable, and likely to deviate from even the most simple principles." They scorned the armorers as primitive creatures, incapable of reason, blindly following traditions propagated from generation to generation. In fact, the very industriousness of the armorers, their "greed" and their interest in their trade, continually frustrated the engineers. One inspector observed with exasperation that when a sudden (and profitable) order arrived, an armorer could produce more in one or two weeks than he had in the preceding months.[35]

[33]On artisanal entrepreneurship in the ancien régime, see William Reddy, *The Rise of Market Culture: The Textile Trade and French Society, 1750–1900* (Cambridge, 1984), pp. 19–47.

[34]S.H.A.T. 4f5 Danzel, "Etat et dénombrement," January 1, 1782. A.D.L. 930(2) Dubouchet, "Dénombrement des ouvriers," and "Tableau des ouvriers," 18 nivôse, year II [January 7, 1794]. Maguin, *Armes*, p. 45.

[35]Montbeillard, "Mémoire," in Jean-Baptiste Galley, *L'élection de Saint-Etienne à la fin de l'ancien régime* (Saint-Etienne, 1903), p. 390. S.H.A.T. 4f12 [Agoult], "Mémoire sur des épreuves de batterie de platines," January, 1769.

The engineers deplored this and were determined to make Saint-Etienne more like its centralized northern sisters. But 18th-century arms merchants proved unwilling to invest in production. They were content to supply artisans with raw materials and buy back semifinished products for further processing. So long as merchants were at the mercy of erratic military demand and artisans who could shift production to the private sector, return on capital was too uncertain to justify a heavy outlay of capital.[36]

This raises the converse question: why didn't artisanal producers eliminate the merchants? After all, the knowledge needed to coordinate the different branches of the trade was available to many artisans. Indeed, the boundary between master artisan and petty merchant was highly fluid, and they were often linked by kinship. Both groups, however, were held in check by the wealthy *négociants* who controlled access to raw materials and to the market. In particular, those *négociants* who became *entrepreneurs* derived great advantage from their legal monopoly on military contracts because it enabled them to take advantage of the irregularity of wartime contracts. This happened because large military orders tended to coincide with a drop in civilian demand as war cut off foreign markets. In the 1750s, for instance, the *entrepreneurs* were able to contain their rivals and bind armorers to them with debts.[37]

Yet the *négociants* never succeeded in wholly dominating the economic terrain either. The "sweated alternative" never materialized in Saint-Etienne.[38] Indeed, when the market was properly aligned (as in the early 1780s), the armorers and petty merchants were able to turn the tables on the *entrepreneurs* and undermine the Royal Manufacture. This reminds us that artisans and merchants did not experience the market as an impersonal force, but through face-to-face social relations that expressed the relative power of big merchant and little merchant, merchant and artisan, master and journeyman. And although these "forces" were partially set into motion by faraway buyers and sellers, they also reflected the actions of local agents: their efforts to open new markets, their appeals to Parisian ministers for tariff protection, and their threats against those who violated the norms of the local culture.

In this context, the challenge for armorers and merchants (both

[36]Tellingly, the lauded northern manufacturers needed constant refinancing in the latter part of the 18th century. Bonnefoy, *Armes de guerre*, pp. 237–68.

[37]Josette Garnier, *Bourgeoisie et propriété immobilière en Forez aux XVIIe et XVIIIe siècles* (Saint-Etienne, 1982), pp. 106–25, 145–51, 252–54, 476–77, 479–83.

[38]For the "sweated alternative," see Tessie P. Liu, *The Weaver's Knot: The Contradictions of Class Struggle and Family Solidarity in Western France, 1750–1914* (Ithaca, 1994).

large and small) was the "problem of coordination": how to organize their efforts in the face of these multiple uncertainties. The difficulty was that Saint-Etienne lacked the formal corporate structures which usually performed this function in the artisanal trades of the ancien régime. The only formal institutions to guide economic life were those introduced by the state engineers to get the sort of guns they wanted: the proof house and the reception room for gunlocks. Only gradually were local producers able to make these institutions serve their own ends. Conflict over standards is the by-play of a conflict over who controls the proceeds of production. For it is here, where the problem of command meets the problem of coordination, that the artifact takes shape.

Gauges and Gunlocks

In 1777, the Gribeauvalists not only introduced a new musket model; they also entered into a new direct managerial relationship with the armorers. For the first time, the state set prices for gun parts, rather than buying the finished gun. Along with this managerial relationship, the artillerists also introduced new techniques of production and sharply tightened quality controls. The unintended result was to greatly exacerbate long-standing frictions and to drive the armory into rebellion and ruin.

One immediate effect of this reform was to greatly diminish the authority of the *entrepreneurs* over production. Henceforth they received only a fixed fee for their financial services. The *entrepreneurs* protested: setting prices by command could never replace the dealings of interested parties. "Military formations," they argued, "may depend on the will of single person, [but] everyone has influence on the permutations of commerce." The state, they noted, lacked the necessary information to set prices for gun parts. Indeed, these prices were not calculable. Didn't the engineers know that all armorers were not equally skilled? And that not all orders—even from the government—were identical? As a third party, "uninterested" in the outcome of the exchange, the state had no business involving itself in the details of the trade.[39]

Against this vision of an economy driven by myriad private contracts, the engineers offered a vigorous program of state-run managerialism. The newly appointed inspector, Pierre-André-Nicolas

[39]These objections date back to 1759–60, when the state first briefly tried this managerial method. S.H.A.T. 4f3/1 [Entrepreneurs de Saint-Etienne], "Extrait d'un mémoire donné au Ministre de la Guerre," June 6, 1760. A.M.StE. HH12 "Concernant les nouveaux règlements établis dans la Manufacture de Saint-Etienne," [1759].

d'Agoult, calculated the component prices of the musket by breaking the manufacturing process down into dozens of analytical tasks. For each he assessed the wage and material costs. Inaccurate as his estimation proved to be, it marked a milestone in the evolution of modern management—an innovation that owed more to French bureaucratic rationalism than to the private sector's drive for profits.[40] The Gribeauvalists also sought to define the qualifications of arms workers and establish fixed work rules—what the 18th century called the "police" of the manufacture. Henceforth, armorers needed the inspector's approval to take on apprentices, journeymen were forbidden to change shop without consent, and private arms merchants were forbidden to "seduce" military armorers with offers of more remunerative contracts.[41]

The Gribeauvalists' purpose in all this was to transform the processes by which guns were made. Saint-Etienne employed distinctive work practices, different from the two northern armories. The service now insisted on a "perfect uniformity in all three manufactures." The task of preparing the technical means for this synchronization fell to Honoré Blanc, designer of the M1777. As chief controller of all French armories, Blanc was now charged with seeing that all the armorers were "provided with the various tools and instruments necessary to assure the uniformity of the work, acceleration of production, and economy in price."[42]

The state-salaried controllers who actually wielded these instruments of inspection at Saint-Etienne were the crucial links in the chain of command that ran from the state to petty producers. The artillerists conceived of them as the noncommissioned officers, or NCOs, of the manufacture: men elevated from the ranks of the soldiery to relay the orders of their superior officers. And just as Enlightenment military reformers curtailed the entrepreneurial role of NCOs, so did the artillerists seek to make the controllers subservient to an established hierarchy. Inspector Montbeillard called them "the eyes of an inspector"—but added "that one could say, with the proverb: *You shouldn't always believe your eyes.*" Despite a state salary of one thousand livres a year they had long acted as entrepreneurial

[40]S.H.A.T. 4f3 "Tableau du temps employé à la fabrication des pièces d'armes dans les différentes Manufactures" [1770s]. Compare with Alfred Chandler, *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, Mass., 1977).

[41]Steven L. Kaplan, "Réflexions sur la police du monde du travail, 1700–1815," *Revue historique* 261 (1979): 17–77. "Règlement de 26 février 1777," reprinted in Gras, *Armurerie* (n. 31 above), pp. 42–48.

[42]S.H.A.T. 4f5 [Gribeauval], "Mémoire," October 29, 1781.

agents in their own right, involved in under-the-table dealings customary at Saint-Etienne. Before the arrival of the Gribeauvalists in 1763, for instance, the controller of gunlocks collected an illicit three sols "premium" for approving a lock.[43]

One of these men ("more interested in his pocketbook than his duties") was Joseph Bonnand, whose family had quasi-hereditary rights to the position. Bonnand paid armorers according to his estimation of the quality of their work. This qualitative judgment depended less on the individual lock than on the artisan's reputation, his personal relations, and pattern of delivering good locks in the past. A sign of this personal judgment is that Bonnand obliged locksmiths to deliver workpieces to him in his own house. This discretionary power made him an important patron in his own right. Control over standards is control over access to the market.[44]

The Gribeauvalists found these activities intolerable; "premiums" sapped the controllers' willingness to reject faulty arms. They also highlighted their discretionary power over the workers. On taking charge of the armory in 1763, the Gribeauvalists had made a clean sweep of personnel; Bonnand was replaced with Honoré Blanc.[45] The underlying problem was that controllers shared the passions, rivalries, and personal interests of the workers "to whom they are bound by blood, by marriage, and by friendship." These familial, trade, and class loyalties frustrated the artillerists.[46] The problem of command was caught up in the social relations of the armory. So in the place of social relations, the engineers substituted objective measures.

This was not an easy undertaking. Master drawings of the M1777 were not composed until 1804 (see fig. 1). All that appeared in 1777 was a list of the dimensions of the gun's parts. The difficulty of compiling these specifications reminds us of how hard it is to master thick objects. Consider the tumbler, which the artillerists referred to as the "brains" of the gunlock because it controlled the transfer of the spring's force to the cock. Even after assigning numerical values to nine of the principal dimensions of the tumbler, its contour remained ambiguous. Officers debated whether the length of the

[43]S.H.A.T. 9a10 Vallière, père, to Chamillart, November 10, 1728. S.H.A.T. 4f12 Montbeillard, "Mémoire," August 16, 1763; and "Mémoire sur les platines," May 6, 1764.

[44]S.H.A.T. 4f7/1 [Bellegarde], "Mémoire," 1765. S.H.A.T. 4f3 "Examen des raisons qui ont rendu susceptible d'augmentations plusieurs pièces" [1777?]. Denis Descreux, *Notices biographiques stéphanoises* (Saint-Etienne, 1868), pp. 63–64.

[45]Montbeillard, "Mémoire" (n. 35 above), 386–90. S.H.A.T. 4f7 Montbeillard, "Mémoire," August 1763.

[46]S.H.A.T. 5a9/1 [Agoult?], "Mémoire," 1777.

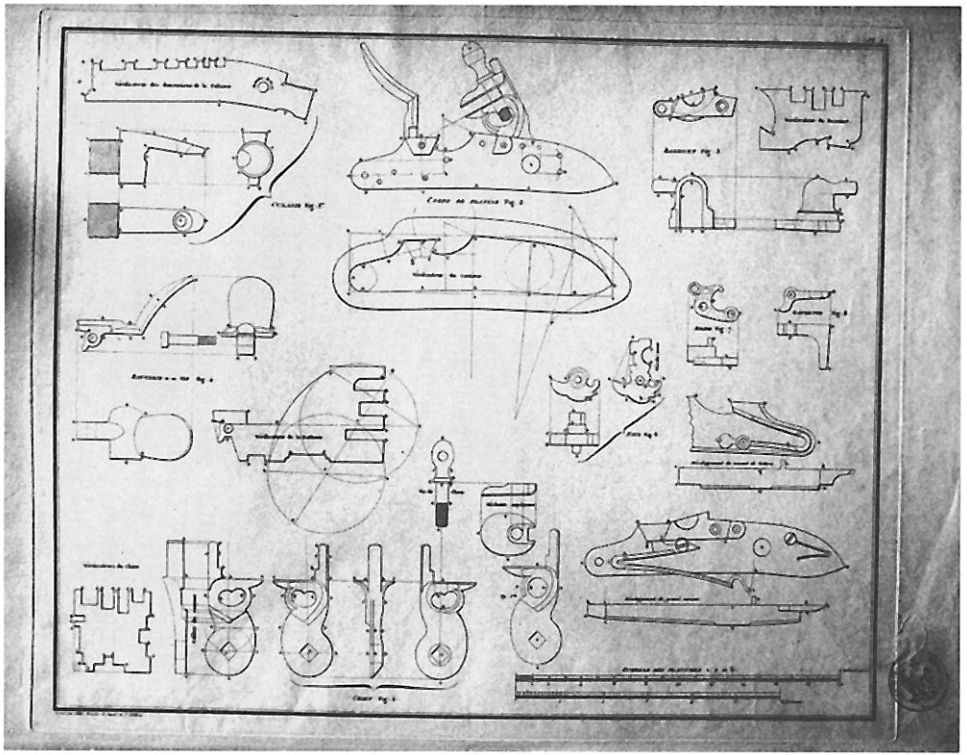

FIG. 1.—Technical drawings for the modified M1777 musket, year IX [1802–1803]. This set of official drawings accompanied the promulgation of the new musket model. It illustrates how engineering plans had begun to offer rigorously interrelated orthogonal views. It also shows how artillery officers used geometrical constructions to define the shape of lock parts. See, for instance, the traces that inscribe the various dimensions of the lock plate (*corps de platine*) pictured in the top center. The two views of the tumbler (*noix*) in the center left are accompanied by a view of the tumbler's gauge. The final plans were not published until 1805. These drawings were once held in S.H.A.T. 4f22 Min. War, *Règlement fixant les principales dimensions des armes portatives, suivant les dernier modèles arrêtés* (Paris, ventôse, year XIII [February-March 1805]). Unfortunately, they are no longer in the archives, and I owe this photo to the kind assistance of Louis Viau of *Gazette des armes.*

"claw" of the tumbler should be 4.75 *lignes* or 5.00 *lignes*. This distance was critical to whether the tumbler engaged the spring. And what of the contour of the claw, which also affected the lock's action? In 1804, the engineers would try to define this contour by using geometric constructions, inscribing it within a circle traced from the pivot. But the claw was not perfectly circular; indeed, it could not be circular if the lock were to function properly. Blanc had always admitted that lock-making required "much intelligence" from the worker; yet he also claimed that the goal of production was "perfection." The engineers resolved this tension between the goal of uniformity and the unspecifiability of the artifact by defining acceptable tolerances for the tumbler's dimensions with the use of gauges and jigs.[47]

A surviving set of master gauges for the M1777 is almost certainly the work of Honoré Blanc (see fig. 2). These instruments are themselves a remarkable achievement. There was no equivalent in the United States for another forty years, and in private industry such gauges were still rare in France in the late 19th century. Moreover, these master gauges were only the beginning. A set of pattern guns (*types*) distributed to each manufacture was used to calibrate a set of gauges and jigs supplied to each artisan. From these, each artisan was to make a set for his own daily use.[48] These gauges defined the physical shape of the gun, and limited the artisan's freedom to control the production process. They also reduced the discretion of the controller. In this sense, Blanc built his supervisory duties directly into these instruments. Since 1763, he had been traveling to scattered workshops to instruct the locksmiths in the use of gauges. His goal was to proceed until the armory operated as if each worker had "the same gauge." Bemoaning a shipment of inadequate muskets that had bypassed the controllers, he announced that the gauges are "our guides and ought to be our laws." In September 1782, he began experiments with the "dies and tools proper to rendering [gunlock] pieces perfectly exact and uniform."[49]

To further discipline the shape of the lock, the engineers also

[47] For the debates over gun dimensions in 1804, see S.H.A.T. 4f22 Sirodon, "Mémoires sur les proportions dans les armes," year XIII [1804–1805]; Tuffet Saint-Martin, "Observations sur le règlement," year XIII [1804–1805]; C. G. Dufort, "Observations sur le règlement," year XIII [1804–1805]. S.H.A.T. 4f7 [Blanc et al.], "Mémoire sur la fabrication des armes à feu à la Manufacture de Saint-Etienne," 1777.

[48] Smith, *Harpers Ferry* (n. 3 above), pp. 102, 109–10. Cohen, "Inventivité organisationnelle" (n. 7 above). On gauges in the manufactures, see S.H.A.T. 4f3 [Gribeauval], "Circulaire à Montbeillard, Bellegarde, et Minard," March 1766. S.H.A.T. 4f6/3 Agoult, "Projet d'un règlement," [1770s].

[49] S.H.A.T. 4f10 Blanc, "Observations sur 4 cannons," June 24, 1781. S.H.A.T. 6c5 Danzel, "Aperçu des travaux," May 16, 1783.

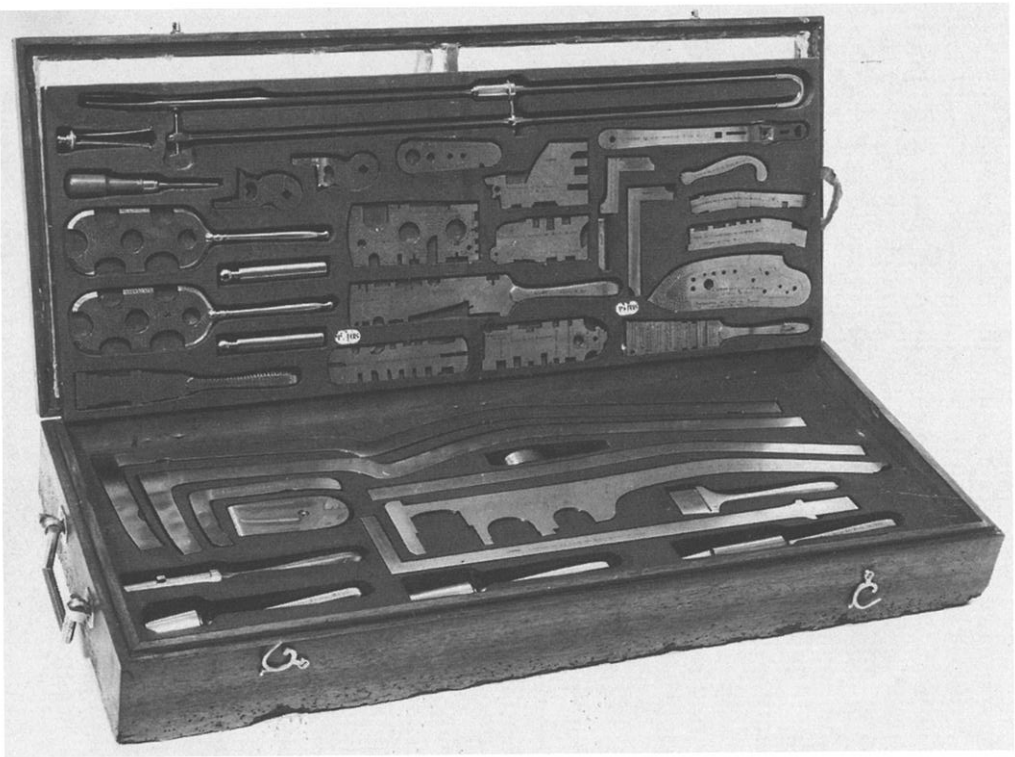

FIG. 2.—Gauges for M1777 musket. This set of gauges is one of the finest examples of precision manufacturing in the ancien régime, and is almost certainly the work of Honoré Blanc. The gauges are primarily of the go-no-go variety, and they thereby defined the tolerances for various dimensions of various gun parts. The gauges are held by the Musée de l'Armée, Paris (P108).

embedded their standards in jigs and machinery. This meant altering the organization of production. Originally, all the lock pieces had been forged and filed by a master locksmith and his journeyman. After 1763, however, the tumblers for military gunlocks were made by two specialists working under close supervision in a central manufactory. There they machined the tumbler's large pivot with a tool which "had the effect of a lathe." This was Blanc's hollow milling machine, the first of its kind, later adapted by Eli Whitney. The workers also used a filing jig, which Blanc introduced in 1765 to position the square "flats." Four different gauges were then used to check the thickness and circumference of the tumbler and the diameter and placement of its axes.[50] The skills of the tumbler-makers were not thereby made superfluous. Nor were the other locksmiths suddenly de-skilled. Their discretion, however, was now hemmed in by gauges, jigs, and the need to make their pieces function in concert with the supplied tumbler. At the reception room in Saint-Etienne a controller examined the play of the finished lock, and then visited each piece individually with a set of gauges. He then reassembled the lock to see that it still functioned. If not, the worker was not paid.[51]

The engineers' conceit that the tumbler was the "brains" of the gunlock is revealing. Their decision to remove the production of this piece from the hands of the artisans and place it under their direct authority is an apt metaphor for the way they hoped to transfer knowledge of the productive process from the atelier to their own offices. This move was actively resisted by the artisans of Saint-Etienne.

Producers and Citizens

The artillerists' commitment to quality certainly produced results—not all of them intentional. In 1782, Agoult crowed that the musket was "at last achieving the desired perfection."[52] But this "perfection" came at a heavy price. The number of rejected locks rose appreciably after 1777, as did the effort that locksmiths had to

[50] S.H.A.T. 4f12 [Agoult], "Mémoire," January 1769. Montbeillard, "Mémoire" (n. 35 above), pp. 386–90. Battison, "Eli Whitney" (n. 3 above), pp. 11–16. On the gauges and jigs, see S.H.A.T. 4f6/3 "Projet de règlement pour la Manufacture de Saint-Etienne," July 21, 1773.

[51] S.H.A.T. MR1741 Blanc, "Mémoire historique sur les progrès," April 27, 1777. S.H.A.T. 4f1 [Agoult], "Règlement provisoire pour la Manufacture de Saint-Etienne," February 26, 1777.

[52] S.H.A.T. MR1739 Agoult, "Mémoire remis à M. de Saint-Sernin," November 14, 1782.

devote to production. Both these changes resulted in increased costs to armorers. Many quit military work and turned to making locks for the civilian market, where prices were rising thanks to the demand for guns by the American revolutionaries. In an effort to retain military armorers, the Gribeauvalists increased the offering price for a lock by 16 percent and the overall price of the musket by 28 percent.[53] Nevertheless, from 1776 to 1781 the annual output of the manufacture fell from twenty thousand to twelve thousand pieces and was sinking further. In desperation, the Gribeauvalists turned to legal powers of enforcement. Artillery officers had long asserted that arms workers had the same legal status as soldiers. Now they began to use military discipline to enforce proper work procedures, hiring practices, and commercial transactions. Inspector Agoult jailed dozens of armorers who violated work standards.[54]

These men, however, were neither soldiers nor helpless day-laborers. They were elite artisans, among the most prominent persons in town. Enraged, the local municipal council took their part. Armorers—even military armorers—paid taxes, had standing with the civilian courts, were domiciled in town, "and consequently belong to the body of citizens." The municipality thereby invoked a notion of citizenship tied to the privileges of city dwellers, but which also pointed to their long-standing demand that economic freedoms not be shackled by legal impediments.[55] And this time, they got a hearing from the highest civilian authorities in the kingdom. In August 1781, the minister of war ordered Agoult to moderate his discipline of the armorers, and soon afterward the steely inspector was replaced by Danzel de Rouvroy. Then, on January 17, 1782, the civilian authorities in Paris authorized the creation of a separate proof house for armorers making guns for the civilian market, with a civilian proof master to be elected by a body of local syndics. This local control over standards gave the town its first formal mechanism for coordinating the gun trade, the sort of institution Sabel and Zeitlin argue is intrinsic to the operation of industrial districts. This victory also established the political and economic alliance of master artisans and petty merchants that governed the municipality through the early years of the Revolution.[56]

[53]S.H.A.T. 4f3 [Blanc] to Gribeauval, February 1, 1778.

[54]A.N. F12 1309 "Ouvriers mis en prison par Agoult," [1781].

[55]A.M.StE. 1D1 Conseil Municipal, *Registres*, October 2, 1781. A.N. F12 1309 Neyron et al. to Contrôleurs-Généraux, December 29, 1780.

[56]"Règlement pour la police de la Manufacture d'Armes établie à Saint-Etienne," January 17, 1782, in Roland de la Platière, *Manufactures, arts et métiers* (n. 31 above), pp. 49–50. Alder, *Engineering the Revolution* (n. 10 above), pp. 213–20.

This measure, however, crippled the power of the engineer-inspectors over civilian armorers. Inspector Danzel continued to incarcerate those military armorers who failed to furnish promised work "done with the requisite precision." And Louis XVI himself signed an arrest warrant for the notorious Joseph Bonnand, who had "raged against the regulation and authority of the officers."[57] But military armorers could now shift their work into the civilian sector without fear of retribution, and by 1785 the prize armory of the kingdom was on the verge of ruin.

What could the artillery engineers do in this dire situation? Inspector Danzel thought he knew. He proposed that the state buy out the *entrepreneurs* and run the armory on the *régie* system. A nationalized industry would operate from a centralized factory; armorers could be hired on a contract basis; and the artillery inspectors would manage the whole business professionally. This was the logical outcome of a century-long effort to put the state in direct contact with armorers.[58] In a lengthy memorandum to the minister of war, Gribeauval rejected this approach. The king would be unwise to buy out the armory and absorb the risks of fluctuating demand. Besides, Gribeauval did not want his professional artillery officers involved in the sort of commercial transactions a *régie* would entail, such as selling rejected gun barrels to the slave trade. But neither could he condone any relaxation in standards. As a stopgap solution, therefore, he decided to entice the *entrepreneurs* to increase production by offering them a guaranteed return on capital, known today in military-industrialist circles as "cost-plus." This program backfired, however, and output plummeted even further. As for the long run, Gribeauval proposed a techno-fix solution that would replace the need for workers' skills altogether: the manufacture of firearms with interchangeable parts.[59]

Evaluating Interchangeability

There was nothing new about the idea of interchangeability in the mid-1780s. Blanc was not the first to achieve interchangeable parts production; he was not even the first French armorer. In the 1720s, Christopher Polhem, a Swedish inventor, manufactured clocks composed of interchangeable parts. For this feat, Polhem has been often

[57]S.H.A.T. 9a11 Danzel, "Mémoire," June 3, 1782. Louis XVI, "De par le roi," June 15, 1782.

[58]S.H.A.T. 4f7 Danzel, "Décadence de la Manufacture," September 19, 1784.

[59]S.H.A.T. 4f3 Gribeauval to Ségur, June 5, 1785.

described as a lone technological visionary.[60] But at the same time, in France, an armorer-inventor named Guillaume Deschamps was manufacturing gunlocks with interchangeable parts for the French army.[61] What Robert Gordon has called the "mechanical ideal" has long appealed to artisans devoted to perfecting their craft; the trick was making it a technical reality, and that was to prove a daunting institutional challenge.[62] By the 1780s, the Gribeauvalists already had decades of experience making artillery carriages with this method. In the same letter in which Gribeauval repudiated a nationalized armaments industry, he asked the War Office to fund the further development of Blanc's technology in the Vincennes dungeon, far from the hostility of Saint-Etienne. He hoped eventually to institute the method in all the armories.[63] The artillery offered several rationales for why the state should undertake this program.

To begin with, the Gribeauvalists claimed interchangeable parts manufacturing would cut production costs. The price of a musket had doubled since 1763. With the war in America winding down, the budget for firearms had fallen from 1.2 million livres in 1783 to one hundred thousand livres in 1785. The artillery leadership hoped to mitigate these cuts with "the techniques of Sr. Blanc." These savings would result from replacing skilled artisans with semiskilled laborers, generating a "real and considerable reduction in the price of arms . . . due to the infinite abridgment of labor costs."[64] This assumed, of course, that the cost of engaging skilled mechanics to construct new machinery would not outweigh the savings expected from substituting cheap laborers for skilled armorers. Moreover, mechanizing any single task would provide only marginal savings at best. Only system-wide interchangeability would save substantial amounts by eliminating the need for a final, expensive hand fitting. This would require a significant outlay of capital. Now that the entrepreneurs no longer set prices for gun parts, they would not realize these savings. And for their part the armorers understandably opposed such an investment. Hence, the logic of cost savings through uniformity production appealed only to the state. The problem was that, in the late 1780s, the crown

[60] William A. Johnson, ed. and trans., *Christopher Polhem: The Father of Swedish Technology* (Hartford, 1963).

[61] S.H.A.T. 6c5 "Etat des épreuves de Deschamps" [1727]. The sole published reference to Deschamps's work is Jean-Jacques-Basilien Gassendi, *Aide-mémoire à l'usage des officiers d'artillerie de France*, 5th ed. (Paris, 1819), p. 591.

[62] Gordon, "Mechanical Ideal" (n. 25 above).

[63] S.H.A.T. 4f3 Gribeauval to Ségur (Min. War), June 5, 1785.

[64] Ibid.

was in no position to make that kind of investment. Funding for Blanc's efforts took up nearly 15 percent of the annual budget for firearms in the years 1785–90, for a total of nearly eighty thousand livres. Yet even these funds—given begrudgingly—were insufficient to equip a full-scale factory.[65]

The artillerists also argued that by facilitating repairs, interchangeable parts reduced costs over the lifetime of the musket. Salvaging and refitting old locks constituted a significant drain on the arms budget. Yet here again, economizing on these repairs did not interest producers, only the state—and would require a full-scale conversion.[66]

In the face of these obvious diseconomies, historians have usually explained the military's sponsorship of interchangeability as an attempt to realize operational advantages on the battlefield. The French artillerists certainly argued that interchangeable parts would speed repairs and hence augment the fighting ability of troops. This ignored several problems. The spare parts had to be readily available on the site or cannibalized from other guns. But the number of interchangeable weapons was never more than a tiny percentage of the total, nor were they marked as such. Even in the early 1800s, when Blanc's Roanne factory produced ten thousand interchangeable gunlocks a year (perhaps 5 percent of the imperial total), he was not allowed to inscribe the name of his manufacture on the lock plate.[67]

Each of these rationales explains why the state, and not private investors, was interested in interchangeable parts production. But none fully explains the timing and character of the artillerists' program. The uniformity system emerged as part of the Gribeauvalists' larger effort to consolidate their authority over the armory at Saint-Etienne. The challenge they faced there stemmed from the disruption to military gun production caused by the civilian gun sector's competition for skilled labor. The uniformity system, by transforming the sort of labor used to make guns, would prevent artisans

[65] S.H.A.T. MR1739 "Dépenses annuelles de l'artillerie" [1788]. S.H.A.T. 6c5 Note by Gribeauval, in Danzel, "Aperçu des travaux," May 16, 1783. For the accounts, see S.H.A.T. MR1739 Rolland de Bellebrune, "Mémoire concernant la comptabilité," September 28, 1790. For the economics of interchangeability, see Russell I. Fries, "British Response to the American System: The Case of the Small-Arms Industry after 1850," *Technology and Culture* 16 (1975): 377–403.

[66] S.H.A.T. MR1739 Rolland de Bellebrune, "Mémoire," September 28, 1790.

[67] S.H.A.T. 6c5 F. M. Aboville, père, to Narbonne (Min. War), January 27, 1792. S.H.A.T. 6c5 Régnier et al., "Expérience faite . . . sur cent platines," 15 germinal, year XII [April 5, 1804].

from selling their wares to the highest bidder and operating as petty entrepreneurs. It would also reduce the discretion of the controllers and sideline the *entrepreneurs*. The artillerists hoped that minimizing the human discretion interposed between the conception of the artifact and its realization would prevent these venal agents from holding the state ransom with their skills and capital. Inspector Danzel repeatedly argued as much. And several artillerists saw the interchangeability system as implying a new government-owned manufacture: "And so the state would cease to be dependent on the *entrepreneurs* of the manufactures and would no longer have to pay that multitude of supervisors known as controllers, examiners, et cetera."[68]

The "worker-less" factory has been part of the engineering mentality since the Enlightenment. What has been less often noted is that it was originally conceived as an "entrepreneur-less" factory as well. The close tolerances necessary to achieve interchangeable parts would oblige the armorers to work to the engineer's specifications. Building command into the production process would solve the problem of finding controllers able to honestly supervise their fellows. And the rational analysis of production would obviate any need for coordination by merchants. This technocratic ideal presupposed that the relationships between professional engineers and semiskilled workers would be mediated solely by technical drawings, gauges, jigs, and machinery. Against our familiar vision of an Industrial Revolution fueled by the entrepreneurial drive for profits, we need to consider this engineering vision of industrial modernity. Interchangeable parts manufacturing was originally proposed as an alternative to capitalist production. This may not have been a model destined to succeed—but even its failure would have important consequences. Understanding that failure will highlight the character of capitalist industrialization as it did emerge in 19th-century France.

Entrepreneurial Interchangeability

Despite the publicity Blanc generated in the early years of the Revolution, his proposal for a national armory came to naught. Academicians and military commissioners praised his methods and confirmed that Blanc could produce guns with interchangeable parts. But these commissioners worried about the social effect of substitut-

[68] S.H.A.T. 4f7 Danzel, "Décadence de la Manufacture," September 19, 1784. S.H.A.T. MR1743 Dubois d'Escordal, "Mémoire sur la constitution et manufacture d'armes à feu," [1788–90]. Quote from S.H.A.T. 6c5 [Givry et al.], "Précis des motifs qui ont fait autoriser le Sr. Blanc," January 1792.

ing cheap labor for skilled artisans in the climate of revolutionary France. A new manufacture, they feared, would reduce the activity of the old armories to the point where "the work would languish and the former gunsmiths fall into poverty." The commissioners feared that once the armorers got wind of the proposal, their reaction would be violent.[69]

His proposal rejected, Blanc decided to pursue interchangeable parts manufacturing as a private *entrepreneur,* selling guns to the army. The huge levies of the revolutionary wars had increased the state's need for muskets. In late 1793, the revolutionary government began setting up its own manufacture of muskets in Paris. This was to be the largest "crash" industrial project Europe had ever known. Within a year, Lazare Carnot and the other engineers who directed this mammoth effort from the Committee of Public Safety also began to experiment with interchangeable parts manufacturing. That effort ended with the Thermidorean coup.[70] In the meantime, however, the National Convention had allowed Blanc to purchase a convent in the town of Roanne for use as a workshop, plus the nearby Alcock mill, site of one of France's most impressive factories (for the manufacture of buttons).[71] The hope was that Roanne—only 50 kilometers north of Saint-Etienne—could draw on the human and natural resources of the region without provoking the hostility that uniform production had encountered in Saint-Etienne.

By September 1797 Blanc had produced roughly four thousand interchangeable gunlocks at Roanne. By 1800 he had shipped eleven thousand five hundred.[72] In 1801, with Blanc near death, the *entrepreneur* Jean-François Cablat bought out the manufacture and contracted to deliver twelve thousand muskets a year. Five out every one hundred gunlocks were to be tested randomly for interchangeability. Until the manufacture was closed in 1807, output averaged roughly ten thousand gunlocks and two thousand muskets per year. During those same years, by comparison, Eli Whitney was failing to meet his contracts for far fewer muskets, and his gunlocks were not,

[69]Jean-Baptiste Le Roy, Pierre-Simon Laplace, Charles-Augustin de Coulomb, and Jean-Charles de Borda, *Rapport fait à l'Académie Royale des Sciences, le samedi 19 mars 1791, d'un Mémoire important de M. Blanc* (Paris, 1791). S.H.A.T. 6c5 Givry et al., "Résultats," [November 1791].

[70]Alder, *Engineering the Revolution* (n. 10 above), pp. 253–91.

[71]*Archives Parlementaires,* 77 (October 25, 1793): 524–25; 78 (November 1, 1793): 134–35. François-Alphonse Aulard, ed., *Recueil des actes du Comité de Salut Public,* vol. 11 (Paris, 1897), pp. 590–91.

[72]S.H.A.T. 6c5 Blanc to Min. War, 3 jour comp., year V [September 19, 1797]. Blanc to Commission Intermédiaire du Comité Central de l'Artillerie, 26 prairial, year VIII [June 15, 1800].

in fact, interchangeable. By any technical measure, Blanc's factory was an extraordinary achievement.[73]

It achieved this success by amplifying and intensifying the methods used at Vincennes. Each milling machine at Roanne performed a specific task, increasing the accuracy of the machines and minimizing hand-finishing. Making the gunlock involved 156 steps; the lock plate alone required 32 separate tasks, and the tumbler 22. This relentless division of labor is indicative of Blanc's analytical approach.[74] There were, however, several limitations to Roanne's achievement. First, attempts to render the whole gun interchangeable proved premature; lathes capable of turning irregular surfaces, such as the gun stock, were unavailable. Second, only those locks mounted at Roanne were interchangeable; those shipped untempered to other manufactures might not be. Third, the Roanne manufactory continued to employ "adjusters and correctors of the gunlock pieces" who checked the fit of the locks before handing them over to the controllers; call them what you will, they functioned as fitters. And fourth, the controllers at Roanne actually had "twenty times" as much work under the new system because they were obliged to gauge and measure a large number of parts. Rather than substituting mechanical controls for personal oversight, the system demanded even greater administrative supervision.[75]

All this points to the central limitation on the Roanne system: artisanal skills remained essential to production. The resulting failure to realize major savings in labor costs meant the factory never turned a clear profit. Between 1800 and 1804, the Roanne factory produced interchangeable gunlocks for a price about 20 percent more than at Saint-Etienne.[76] Thanks to patrons in the artillery, Blanc received a 27 percent subsidy per lock. The state also provided conscript labor

[73]The accounts of the Roanne factory under Cablat have survived; see B.M.R. 3R2 "Journal général de la Manufacture Nationale d'Armes de Roanne, Commencé le 7 nivôse, an X" [December 28, 1801]. S.H.A.T. 4f2 Cablat and Min. War, "Traité pour l'entreprise," 30 fructidor, year X [September 17, 1802]. S.H.A.T. 4f6/4 Tugny, "Mémoire sur la Manufacture," messidor, year XI [June–July 1803]. Woodbury, "Eli Whitney" (n. 2 above).

[74]S.H.A.T. 4f6/4 Tugny, "Mémoire sur la Manufacture," messidor, year XI [June–July 1803]. S.H.A.T. 4f4 Tugny and Cablat, "Devis des prix," 29 fructidor, year XI [September 16, 1803].

[75]S.H.A.T. 4f6/4 Tugny, "Mémoire sur la Manufacture," messidor, year XI [June–July 1803]. S.H.A.T. 6c5 A. G. Aboville, fils to F. M. Aboville, père, 7 ventôse, year X [February 26, 1802]. Régnier et al., "Expérience faite . . . sur cent platines," 15 germinal, year XII [April 5, 1804].

[76]S.H.A.T. 6c5 Tugny, "Mémoire présenté au Conseil d'Etat," 16 vendémiaire, year XII [October 9, 1803]. B.M.R. 3R2 "Journal général de . . . Roanne."

and low-interest loans.[77] But this only made Blanc's factory vulnerable to the enmity of a powerful new faction in the artillery bureaucracy led by Napoléon's crony and former superior, Jean-Jacques-Basilien Gassendi. When the War Office was reorganized in 1800, Napoléon made Gassendi the director of the Division of Artillery. From this position of power he was eventually able to shut down the Roanne Manufacture.[78]

Why, after four decades of commitment to "rational production," did the artillery under Gassendi repudiate interchangeable parts manufacturing? After all, to argue that the method "did not pay" hardly answers the question. The difference between the cost of gunlocks from Roanne and from Saint-Etienne was never that great. All the French armories depended on government subsidies of some sort. And during the same period, the United States government—no friend of state expenditures—underwrote gun production with its "armory system." Yet Gassendi and his partisans denied that interchangeability was achievable, affordable, or desirable. Why did they do so, and how did they triumph?

Technological Memory and Technological "Facts"

The bitter bureaucratic battle over interchangeable parts manufacturing in the early 19th century was part of a contemporary effort by Napoleonic elites to redefine the French state after the trauma (as they saw it) of the Revolution. The Napoleonic solution was to harness local elites and popular classes to the national purpose primarily through the mechanism of the "warfare state."[79] Generally, the armaments trade flourished under this arrangement. Yet there remained the crucial question of how to divide the spoils. This depended on the accommodation reached by commercial and military elites with distinct interests. The debate between the "Gribeauvalists" (now led by his successor, François-Marie d'Aboville) and Gassendi's party reflected divergent views on how postrevolutionary France should be governed. The guns of the Napoleonic era reflect this political struggle.

Even the most basic technological "facts" were contested during this intraservice controversy. One central question was apparently a

[77] S.H.A.T. 6c5 Agoult, "Historique des travaux du Sr. Blanc," 13 vendémiaire, year VI [October 4, 1797].

[78] Paul Gaffarel, "Le Général de Gassendi," *Mémoire de la Société Bourguignonne de Géographie et d'Histoire* 19 (1903): 387–459.

[79] Louis Bergeron, *France Under Napoléon*, trans. R. R. Palmer (Princeton, 1981). For state sponsorship of metalworking and armaments, see Denis Woronoff, *L'industrie sidérurgique en France pendant la Révolution et l'Empire* (Paris, 1984).

simple one: could the pieces of Blanc's gunlocks actually be interchanged? To answer it, both sides had recourse to demonstrations along the lines of Blanc's 1790 "proof" in the Hôtel des Invalides. At stake was control over the technological memory of the French state, and hence, whether interchangeability would be judged a "success" or "failure."

Aboville struck first in 1801, demonstrating before the Central Committee of the Artillery that 492 out of 500 locks from Roanne were interchangeable. Armed with this finding, he petitioned Bonaparte to replace the traditional armories with a single rational manufacture. But across the top of this petition, Napoléon scrawled: "[L]et me know the opinion of [Gassendi] on this subject."[80] A week later, a test performed under Gassendi's direction found that only 152 out of the 492 gunlocks were serviceable.[81] Control over technological "facts," it would seem, depended on control over personnel. Twice again, test and countertest followed, while the parties fought intricate bureaucratic maneuvers to control the personnel responsible for Roanne. Aboville sent his eldest son, Augustin-Gabriel, to Roanne as its first official inspector in 1802. However, the next year, Aboville's patronage network collapsed. By 1806, Gassendi simply cashiered the controller who dared to demonstrate that Blanc's methods produced interchangeable gunlocks.[82]

At that very moment, fifty gunlocks with interchangeable parts were on display at the 1806 Parisian Exposition of the Products of Industry. Unlike London's Crystal Palace Exhibition of 1851, which so stimulated the British public, this event passed unnoticed. In short order the gunlock factory was permanently closed.[83] Over the next decade, a few French armories experimented with "accelerated methods," in state manufactures at Versailles and Mutzig, and in private factories under Julien Le Roy and John George Bodmer.[84]

[80] S.H.A.T. 6c5 F. M. Aboville, père, et al., "Procès-verbal de remontage de 500 platines," 17 vendémiaire, year X [October 9, 1801]. F. M. Aboville, père, to Bonaparte (with note by Bonaparte), 16 pluviôse, year X [February 5, 1802].

[81] S.H.A.T. 6c5 Lamogère et al., "Procès-verbaux sur 492 platines," 25 pluviôse, year X [February 14, 1802].

[82] S.H.A.T. 6c5 Jacques et al., "Epreuve faite. . . sur cent fusils," February 12, 1804. Cablat to Min. War, 8 nivôse, year XII [December 30, 1803]. Lefebvre, "Examen fait de cinq platines," 10 prairial, year XIII [May 30, 1805]. Delahaye, "Manufacture Impériale de Platines établie à Liège," 10 prairial, year XIII [May 3, 1805]. S.H.A.T. Xd414 Saint-Martin to Gassendi, November 9, 1806.

[83] S.H.A.T. 6c5 Gassendi to Min. War, November 27, 1806, June 26, 1807. [Gassendi] to Bonaparte, December 9, 1806. Claude Gaier, "Note sur la fabrication des 'platines identiques' et sur la Manufacture Impériale de Platines de Liège," *Bulletin trimestriel des Amis du Musée d'Armes de Liège* 7 (1979): 9.

[84] For Versailles, see Hermann Cotty, *Mémoire sur la fabrication des armes portatives de guerre* (Paris, 1806), pp. 63–75. On Mutzig, see S.H.A.T. 4f6/4 A. M. Aboville,

But Gassendi's manipulation of the process of testing and witnessing meant that for the next fifty years French engineers "remembered" that interchangeable parts manufacturing had been tried—and had failed.[85]

Technological memory, then, at least in the state-led sector, becomes a struggle to control those institutions which sponsor technology. This is not simply because factions in the government directly suppress innovations, but because the uncertainty of these patronage battles makes private investment too risky. As A. G. Aboville, fils, complained, private investors would not sink the necessary capital into a manufacture which relied on the support of a small number of government officials.[86] And the converse was true as well: government officials proved loathe to support technologies opposed by powerful commercial interests. This was certainly the case for interchangeable parts manufacturing.

The Saint-Etienne Armory in the New Regime

Interchangeable parts manufacturing aroused powerful opposition from merchants and artisans because it implied a new social organization of production. Aboville's plan was to supply the core of military need from a state-owned mechanized factory, while forcing small-time artisanal producers into the fluctuating margins of demand. In his private correspondence with his son, he prophesied that Roanne would be "the seed" of a new manufacture run on the *régie* system.[87] But Aboville was not seeking an efficient production regime, so much as a secure one. That way the state would never again be held hostage by the rebellious armorers of Saint-Etienne, as had occurred during the Revolution. Precision manufacturing was social discipline, and the "fit" of Roanne's gunlocks demonstrated the artillery service's mastery of that discipline.[88] That is why Blanc

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cadet, "Rapport sur Mutzig," November 20, 1810. On Le Roy's armory, see A.N. F12 1565 Commission sur la Perfectionnement des Armes, "Rapport sur le fusil modèle de M. Julien Le Roy," [1815]; and S.H.A.T. 6c2/1 Cotty, "Rapport sur le fusil," 4 December 1815. On Bodmer and his subsequent career in England, see J. W. Roe, *English and American Tool Builders* (New Haven, Conn., 1916), pp. 75–76.

[85] Gassendi, *Aide-mémoire* (n. 61 above), 4th ed. (1809), 2: 589–90; 5th ed. (1819), 2: 591–92. Cotty, *Fabrications des armes*, pp. 69–75; *Dictionnaire de l'Artillerie*, vol. 23, Encyclopédie méthodique (Paris, 1822), pp. 185, 337–43.

[86] S.H.A.T. 4f6 A. G. Aboville, fils, "Observations sur le mémoire présenté au Premier Consul," germinal, year X [March–April 1802].

[87] S.H.A.T. 6c5 F. M. Aboville, père, to A. G. Aboville, fils, 13 ventôse, year X [March 4, 1802].

[88] S.H.A.T. 6c5 F. M. Aboville, père, "Conseil Extraordinaire de l'Artillerie, Séance du 24 fructidor, an X" [September 11, 1802].

and Aboville conducted public displays of interchangeability: they were operational proof of their control over the production process.

Gassendi and his supporters offered a very different social strategy for the Napoleonic regime. They argued that assuring the supply of firearms to Napoléon's army (the linchpin of the warfare state) meant re-establishing the artillery's control over the old armories where gun-making expertise resided. To accomplish this, the artillery service needed the acquiescence of the artisanal class and the capital of the wealthiest arms merchants. This industrial policy fit into a broader social strategy by which the state would attach itself to private interests. Those interests were defined as capitalist, with the profits to go to the right people. On these grounds, Gassendi rejected a proposal by two small-time entrepreneurs to produce gunlocks by mechanical means: "But an enlightened government must ally itself with [the gain of] individuals, and in the onerous proposal before us, the government finds no such [alliance]."[89]

In this way, Gassendi defined the relationship between the military and commercial elites, the two most prominent groups vying for the spoils of the warfare state, and reasserted the artillery's role as mediator between the state and local capitalists. That role had been usurped during the Revolution when the Committee of Public Safety put the state's (collective) interest above that of local elites. Between 1793 and 1797, in Saint-Etienne as in Paris, the government had either bought its weapons directly from artisans or organized its own workshops. During this period, the armory of Saint-Etienne—temporarily renamed "Armeville"—was organized as a *régie.* In 1794–95, some five thousand workers, including novices, women, and children, had produced 170,858 muskets. A jury of armorers, selected by the municipal council, approved these weapons, as standards were relaxed. Production was considered a patriotic act. Severe laws defined the workday, forbade breaks on Sundays, and prevented artisans from attending the harvest. These legal and social strictures, however, went hand-in-hand with democratic consultations in which armorer-delegates helped set gun prices.[90] This amalgam of artisanal control and populist state-ownership was anathema to the artillerists, who had been entirely bypassed during this phase of the Revolution.

[89] S.H.A.T. 6c5 Gassendi, "Rapport . . . sur la proposition que font citoyens Poterat et Cabanel," 16 fructidor, year VII [September 2, 1799].

[90] For output, see A.D.L. L835 [Guilliaud], *La fabrication d'armes de guerre à Saint-Etienne* (n.p., [1800]). On the armory during the Terror, see A.D.L. L933 Bonnand et al., "Extrait des registres," 25 germinal, year II [April 14, 1794]. For the relationship between the central authorities and local institutions during the Terror, see Colin Lucas, *The Structure of the Terror: The Example of Javogues and the Loire* (Oxford, 1973).

Under Napoléon—himself an artillery engineer—the state returned to the ancien régime's system of purchasing its weaponry. With the civilian market demolished by war, the armorers had little choice but to heed the directives of the state. In 1799, the contract between the state and the *entrepreneur* was re-established on the basis of the 1777 law, and the police laws of 1781 and 1782 were reinstated. Also, those armorers exempted from army conscription (one fourth the total workforce) were thereby made subject to military discipline. With this legal and commercial leverage, the new *entrepreneur*, Jean-Baptiste Jovin, operated a monopoly more potent than any under the ancien régime. This was statism—an amalgam of private capitalism and statist direction which governed French military-industrial relations into the 20th century.[91]

This Napoleonic conception of proper social relations had its correlate in the qualities to be sought in material artifacts. Where Aboville took precision fit as the measure of his ability to police the social order, Gassendi's partisans claimed to rule by reference to the ideal of harmony. This was not merely a nostalgia for the lapsed social forms of the ancien régime. Harmony was also a sign of proper function. Gassendi's partisans repeatedly stressed that the gunlock was a machine whose parts had to work together. They complained that the advocates of interchangeable parts manufacturing had become so obsessed with precision that they were blind to the operation of the finished mechanism. "Harmony is the *sine qua non* of the gunlock . . .; it follows that the manufacture of gunlocks by machines where the manufacture of each piece is total and isolated cannot succeed unless the pieces are rigorously identical, and it is without question that this kind of identity is a chimera."[92]

In practical terms, then, isolated gun parts—like the isolated workers who made them—could not function as a whole. Gassendi's countertests, by invoking different criteria of judgment, implied a different organization of production. For his coterie, a harmonious piece of hardware was a sign of their ability to govern the social order. These engineers recognized that harmonious social relations in the armory also meant modifying the way they superintended production. One leading artillerist put it this way after his visit to Saint-Etienne in 1806: "We must have at the head of our armories men

[91] S.H.A.T. 4f6/1 Truffet Saint-Martin, "Observations sur les différents régimes," year X [1801–1802]. Colomb, "Observations sur le règlement de police," January 27, 1806. Archives Départementale du Rhône 2H2 *Règlement pour la police* (Saint-Etienne, 1810). Bibliothèque Municipale de Saint-Etienne F609(6) Dubouchet, *Mémoire*, 28 thermidor, year IX [August 16, 1801] (Saint-Etienne, [1801]).

[92] S.H.A.T. Xd234 Charles Lucio, "Liège: Rapport d'inspection de 1808," July 6, 1808.

who are firm and active and enter into every detail with the sacrifice of all their time; but their firmness must be without severity; we must not kill the poor workers for faults of proportion which do not influence the quality of the arm or its [overall] uniformity. We must gently reconcile three interests which are often opposed, that of the state, the worker and the *entrepreneur*. With gentleness, patience and constancy, our guns will always be the best possible."[93]

The upshot of this attitude was that the state would leave control over the methods of production to local negotiations between armorers and merchants. Inspector Pierre Sirodon, in charge of the Tulle armory, explained that engineers now needed to respect the skills of the artisans. To be sure, he admitted, the quality of guns still had to be assured by gauges calibrated against a master pattern. But officers must not succumb to "a fanaticism of measures." Perfect identity was a chimera. The dimensions of the lock plate, say, could not be fully specified, and differed from armory to armory. Even the gauges differed from armory to armory. And as long as gun-making depended on the skills of the armorers, the success of the armory depended on the interest these artisans had in doing the job properly. To insist on narrow tolerances for all dimensions would be prohibitively expensive and drive the artisans to seek other kinds of commerce. Hence, controllers and inspectors could not simply apply gauges mechanically—any apprentice could do that—but had as well to judge the functioning of the gun. This functionality had many aspects, among them fit, reliability, durability, and ease of use, not all of which could be easily quantified.[94]

This shift in the engineers' conception of their role can be interpreted as a pragmatic approach to production during wartime. With the army marching to Moscow, it was not the moment for undue rigor in the armories. However, the shift also signaled a new conception of manufacturing tolerance as a way to reconcile private interest with that of the state. The new play allowed in standards signaled an adjustment in the relationship of state and private industry. The fit of Napoleonic gunlocks reflected this new political calculation. By freeing judgments from objective standards, officers also acquired new discretionary powers to punish recalcitrant armorers. Qualitative judgments of work were recorded, creating a historical record of fidelity and skills. The perfection of any single gun mattered less than the pattern of behavior and personal loyalty.[95]

[93] S.H.A.T. Xd235 Drouot, "Rapport sur la Manufacture," 1808.

[94] S.H.A.T. 4f7 Sirodon, "Mémoire sur les proportions dans les armes," year XIII [1804–1805].

[95] Ibid.

Under these circumstances, interchangeable parts manufacturing was doomed. Indeed, Gassendi's artillery service actually protested when the *entrepreneur* Jovin established new workshops which adopted some of Blanc's techniques (with forty-seven different workers per gunlock). This development bears out Sabel and Zeitlin's recent admonition to historians to stop making clear-cut distinctions among manufacturing regimes, as if producers faced an either/or choice between flexible specialization and mass production. Manufacturers often amalgamate technological practices and adapt machinery to new situations. Maxine Berg has pointed out that this sort of accumulation of minute innovations has generally eluded historians—particularly in the metalworking industries—because it is undramatic and cannot be easily reified by reference to some "mechanical ideal."[96] In such a situation, the official guardians of technological memory cannot help us recover the past. Interchangeable parts manufacturing may have been repudiated as an "ideal," but many of its practices survived. As the story of Saint-Etienne makes clear, however, historians can track the subtle adaptation of gauges, jigs, and fixtures to different circumstances, and thereby reveal shifts in the sociopolitical world of production.

Conclusion: Technological Memory

One of our most common assumptions about technology is that it "stacks." Whether considered as a form of knowledge, a set of practices, or a collection of hardware, technology is said to accumulate. This realm, above all others, is said to be one in which we can accomplish more than our predecessors—thanks, in part, to their efforts. Even scholars who doubt that technological progress is a friend of human betterment still assume that technology is cumulative. And even those historians who place radical disjuncture at the center of technological change agree that new technology builds on old. For instance, in Edward Constant's (Kuhnian) scheme of technological revolutions, innovators must have a thorough grasp of current knowledge (and its limits) to generate new paradigms. Ironically, scholars committed to evolutionary models of technological change come closest to repudiating a simplistic notion of technological accumulation. They recognize that the broken lines of failed in-

[96]Charles Sabel and Jonathan Zeitlin, "Stories, Strategies, Structures: Rethinking Alternatives to Mass Production," introduction to *Worlds of Possibility: Flexibility and Mass Production in Western Industrialization* (New York, 1993). Maxine Berg, *The Age of Manufactures: Industry, Innovation, and Work in Britain, 1700–1820* (Totowa, N.J., 1985).

novations greatly outnumber successful adaptations. Yet this scholarship too ignores paths that seem to lead nowhere.[97]

Underlying this article has been a different assumption, and hence a different kind of history. Among its more radical implications is the possibility that a technology (even a technology today accounted superior) can be rejected, discontinued, and forgotten. The ideal of interchangeable parts production, pioneered in late-18th-century France, was repudiated in the early 19th century. Ironically, it was in the United States that interchangeable parts manufacturing was successfully developed during the first half of the 19th century. There, mechanization—however resented—was not bitterly opposed, and the state proved willing to subsidize the new technology at its arsenals.

A parsimonious explanation for the rise and fall of interchangeable parts manufacturing in France would simply note that the artillery engineers tried the technique because they hoped it would pay—and when it didn't, they dropped it. There is certainly a modicum of truth in this claim. But it ignores a far more fundamental question: how did the criterion of "making it pay" become the determining factor in judging the "success" of a technology? And for whom did the technology have to pay? In this article, I have argued, firstly, that the uniformity system emerged in France as state engineers, in the face of artisanal resistance, attempted to create "objective" instruments to control the productive process. These engineers sought uniform production for various reasons: because of an operational need for more accurate muskets, because of an aesthetic and operational commitment to uniformity, because of a bureaucratic drive to preserve their role as sole suppliers of weaponry, and above all, because they wished to decouple the nation's security from the activities of unruly and money-minded artisans and merchants. But these various motives are less important than the fact the apparatus of rational production—including interchangeable parts manufacturing—emerged out of a process of conflict and negotiation between these engineers, artisans, and merchants.

And I have argued, secondly, that interchangeable parts manufacturing was abandoned in France when the criteria for judging the "success" of a technology began to include the capacity of productive technology to generate profits for local merchant capitalists.

[97]Edward W. Constant II, "A Model for Technological Change Applied to the Turbojet Revolution," *Technology and Culture* 14 (1973): 553–72. Jacques Ellul, *The Technological Society*, trans. John Wilkinson (New York, 1964). Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York, 1990).

This new criterion emerged as part of a social accommodation between the two main groups—bureaucratic elites and provincial capitalists—vying for power in postrevolutionary France. Interchangeable parts manufacturing was then repudiated in France not because it was a technical "failure" but because it ceased to serve as an ideal for organizing the polity. We can read the terms of this political settlement in the physical qualities of artifacts—in this case, in the persistence of hand-fitted guns.

The lesson for historians is that they cannot allow historical memory to be controlled by those guardians of technology who wish to make a single future appear inevitable. Recapturing the history of technological failures—and setting them alongside the story of technological successes—is one way to bring that lesson home.[98]

[98] Skúli Sigurdsson, "Electric Memories, and Progressive Forgetting," in *Whose History, Whose Science? Problems in the Historiography of Contemporary Technoscience*, ed. Thomas Soenderqvist (forthcoming).