

Infrastructure's Industrial Context

How the Telegraph Shaped the Wire Industry (1845–1910)

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ABSTRACT: When US telegraph promoters built their first commercial lines in 1845, “telegraph wire” did not yet exist, and the best wire available proved woefully deficient for telegraphy. By 1910 a robust US electrical-wire supply reflected the combined effects of telegraph-driven demand, international material and mechanical advances, hundreds of wire-related US patents, and broader industrial changes. To analyze that transition, this study introduces a flexible conceptual framework that centers on the telegraph network as infrastructure and examines its industrial context: the historically contingent materials, manufacturing capabilities, and expertise available to network builders. The analysis challenges certain longstanding views regarding the US telegraph’s growth and industrial significance; demonstrates that telegraphy shaped the US electrical-wire industry, to the enduring benefit of telephone and electrical services; and shows that the wired network itself embodied an important industrial phenomenon that can, and should, be distinguished from the applications or uses it enabled.

Introduction

In October 1852, the premier issue of *American Telegraph Magazine* carried a full-page advertisement by John Norton, who announced his intention to offer “every article used in the construction and working of a line of Telegraph.” His New York shop’s extensive inventory ranged from Morse machines to message envelopes; his gilding department could even

NOTE: THESE ARE UNCORRECTED PAGE PROOFS. NO IMAGES HAVE BEEN INCLUDED.

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give “the highest style of finish and ornament to the instruments furnished.” Yet for the essential line wire that linked telegraph offices, Norton said only this: “I think I can offer English and American wire upon as reasonable terms as it can be found in the market.”¹

Norton’s nebulous offer reflected the midcentury wire supply’s embryonic state, especially for telegraphs. Previously, wire’s limited uses had allowed British imports and some smaller-scale US production to fulfill most needs. In the 1840s telegraph-line construction spurred demand for unprecedented quantity and quality, but pioneer telegraphers soon discovered that the best wire available from any source had numerous abject deficiencies for telegraph lines.

How, then, did telegraphers manage to wire the continent or network the nation? Despite wire’s centrality to all wired-network infrastructure, even historians of technology typically leave questions about conducting wire unasked, implicitly taking its availability and utility for granted.² Influential studies examine important network-related business, political, or social themes, but few probe the physical network’s details. Robert Thompson’s *Wiring a Continent* (1947) described the pioneer telegraph’s “shoddy” lines but devoted little attention to the ways that builders resolved material problems; he mainly concentrated on business developments leading to Western Union’s monopoly. Thomas Hughes, in *Networks of Power* (1993), admirably analyzed how small localized lighting systems of the 1880s evolved into large regional power systems in the 1920s and how context shaped their configurations; in starting with small systems, though, he largely bypassed the consequential shift from “no wired system” to “small wired system” that began with telegraphy and established groundwork vital for other wire-dependent services, including distributed electricity. In *Network Nation* (2010), Richard John emphasized political economy’s influence on telegraph and telephone business strategies; he did note that telegraph-line construction posed greater challenges than the Morse patent interests cared to admit, but the network’s physical development largely remained tangential to his primary focus.³

With infrastructure increasingly commanding attention across scholarly disciplines, some authors have put greater emphasis on its material components or underlying continuities. When Michael Schiffer proposed a “cascade” model of invention for complex technologies, he noted that the telegraph machine triggered a cascade of other inventions for “telegraph components,” and he said that “to make wire to demanding specifications

1. “Norton’s Telegraph Rooms,” Back Cover.

2. For clarity, as used here the terms “wired-network infrastructure,” “wired network,” or, simply, “the network,” interchangeably refer to what engineers would call the “outside plant.” Its most basic elements include conducting wires or cables, wire-supporting structures, insulating devices, and specialized hardware.

3. John, *Network Nation*, 46; also see Nye, “Shaping Communication Networks” which centered on various networked devices and their uses.

and in unheard-of-quantities required new production machinery.” This high-level example served to illustrate his model rather than to analyze those specifications or machines, but it did begin to conceptualize the telegraph in terms of the network’s material components.⁴

More recently, Nathan Ensmenger linked computing’s environmental history with information infrastructure’s material and industrial roots in the nineteenth century. He observed that infrastructure’s “primary purpose is to make other technological and commercial activities possible.”⁵ Yet untangling infrastructure from the applications it enables is no easy task—as Brian Larkin pointed out, infrastructure can be “conceptually unruly.”⁶ Consequently, too few studies distinguish infrastructure’s material components from its applications or uses; even fewer link its material history with its industrial context.

Many primary and secondary sources treat the telegraph “machine” as synonymous with the telegraph “system,” which masks the network, minimizes its significance apart from its applications, and overlooks its critical challenges. In *The Telegraph in America* (1879), James Reid did detail line failures and material deficiencies, but other early sources—especially individuals who stood to benefit from the anticipated government buyout of Morse’s telegraph patent—often downplayed line problems and depicted “the telegraph” as an immediate, resounding success.⁷

Regrettably, such overly optimistic depictions have endured. In 1977 Alfred Chandler lent the weight of his scholarly authority to the oft-repeated notion that “the railroad and the telegraph *marched* across the continent in unison.”⁸ In 2001 Ken Beauchamp called the transmission lines “a *minor* problem to Morse,” and in 2012 David Hochfelder said that “Morse’s telegraph *worked* as he had claimed and *soon* became a commercial success.”⁹

Conducting wire’s history shows that the telegraph “marched” nowhere; rather, it stumbled, hobbled, and crawled. From a network perspective, its history reveals prolonged cycles of building and rebuilding, hard-won industrial advances, and individuals who sacrificed life, limb, or

4. Schiffer, “The Devil Is in the Details,” 492; in 2008, Schiffer’s anthropologically rooted “deep structures” model of component-stimulated invention further hinted at wired-network continuities and related inventions. See Schiffer, “A Cognitive Analysis of Component-Stimulated Invention,” 384.

5. Ensmenger, “The Environmental History of Computing,” S14.

6. Larkin, “The Politics and Poetics of Infrastructure,” 329.

7. For some of the tensions between these points of view, see John, *Network Nation*, 34–48.

8. Chandler, *The Visible Hand*, 195, 197, italics added; as Richard John pointed out in “Elaborations, Revisions, Dissents,” 186, “Chandler’s treatment of the telegraph industry was necessarily sketchy, since, when he published *The Visible Hand*, the history of telegraphy remained largely unwritten.”

9. Beauchamp, *History of Telegraphy*, 52; Hochfelder, *The Telegraph in America*, 1832–1920, 2. Italics added to both.

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livelihood trying to make wires “work.” In other words, telegraph wire did not simply materialize—where needed, when needed, or as needed. As the telegraph’s pioneers learned the hard way, midcentury wire makers lacked critical materials, manufacturing capabilities, and expertise that took decades to develop.

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Revisiting telegraph history from a network perspective shows that the telegraph’s needs catalyzed and shaped the US electrical-wire industry, producing crucial benefits and continuities for all wired-network infrastructure. It also shows that the network itself embodied a consequential industrial and economic phenomenon distinct from the applications, services, or institutions it enabled. More than five hundred US patents issued between 1860 and 1910 provide evidence of telegraph-triggered changes related to bare conducting wire.¹⁰ Many detail the often-intractable material and manufacturing problems inventors addressed, and they illuminate the emerging network’s ties with its industrial and social milieux. Along with handbooks, trade journals, catalogs, and other early sources, these patents identify conducting wire’s principal challenges, and they show how inventors, manufacturers, and workers collectively overcame those challenges to produce wire that could reliably network the nation.¹¹

Infrastructure’s Industrial Context

This study introduces and applies an analytical framework for complex network infrastructure that the author calls “industrial context.” This approach distinguishes the physical network from its applications or uses, segments its enormity into manageable functional categories, and exposes historically contingent developments in materials, manufacturing, and related expertise. First, it distinguishes the network from the disparate devices whose use it enabled and treats devices such as the telegraph machine or the telephone instrument as “applications.” Separating the network from its applications deemphasizes devices used at the ends of the wire and highlights infrastructure’s functional “structures.”

A brief explanation of a network’s functional utility helps frame this distinction’s significance. The heart of any networked infrastructure’s “public utility” lies at the intersection of its physical form and its social function—in the network’s capacity to facilitate socially useful movement of some

10. This total excludes nearly 1,100 other patents related to insulated, armored, or specialized electrical conductors or cables. The author identified potentially relevant patent numbers through multiple key-word searches in the patent commissioner’s annual reports (available in US regional patent repositories or online through the Smithsonian Institution’s library) then reviewed PDFs of patent specifications (available online at US Patent Office or through patents.google.com) to ascertain their relevance for conducting wire.

11. Whether network infrastructure was a “breakthrough” invention or a series of minor “improvements” makes a provocative question but lies outside this article’s scope.

kind. Physical characteristics might vary; sewers, for example, differ dramatically from the electrical grid, at least in their structural details. From a functional perspective, however, networks share an underlying conceptual simplicity: *locations*, *links*, and *flow*. *Flow* describes socially useful movement via *links* that connect *locations*. Flow thus puts the “work” in network because, in a physical sense, work only occurs when something moves some distance. For wired-network infrastructure, conducting wire physically linked locations and enabled the electrical flow that imbued telegraphs, telephones, and other electrical applications with their social utility.

Conceptualizing a network’s functional structures as locations, links, and flow also helps delineate large-scale physical phenomena into manageable analytical units without losing sight of the extraordinary material volumes they incorporate. Such volumes show that the materials needed to wire the continent or network the nation also demanded mass-production capabilities—even if wire was not a mass-market product in a consumer sense. In sum, focusing on the network’s industrial context shifts analytical attention from applications that the network “enabled” to the materials, manufacturing capabilities, and expertise that the network “required” to fulfill its core social function; it thus allows us to distinguish the network’s industrial relevance from its enabling role for applications.

Nothing about this framework conflicts with analytical approaches that emphasize the social construction of networked or other technologies. Rather, industrial context complements social approaches by emphasizing the availability—or lack—of needed materials, machines, and knowledge as key factors that mutually shape technologies and industries. For wired-network infrastructure, industrial context reveals the symbiotic relationship between the network and the conducting-wire industry, with the network operating as both a driver and a beneficiary of important industrial changes.

Telegraph Wire’s Challenges

When the first commercial telegraphs took shape, “telegraph wire” did not yet exist, and wire had few common uses. The earliest telegraph promoters built lines with made-to-order copper wire, but then-insurmountable technical hurdles soon forced them to find alternatives. Copper initially seemed a logical choice, because eighteenth-century electrical enthusiasts had long used copper wires in experiments and demonstrations, as had nineteenth-century electrical-telegraph inventors. In 1837 the British firm Enderby Brothers made copper wire for the first railway-telegraph line built by William Cooke, and in 1843 Stephens & Thomas of New Jersey made copper wire for Samuel Morse’s government-funded demonstration line.¹² Both Cooke and Morse resorted to

12. Hubbard, *Cooke and Wheatstone and the Invention of the Electric Telegraph*, 43–44; Shaw, *History of Essex and Hudson Counties, New Jersey*, 890g.

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stringing copper overhead when their preferred underground arrangements failed, and commercial telegraphs followed suit, including the Morse-licensed Magnetic Telegraph Company (“Magnetic”) in 1845.

Although copper conducted electricity well in sheltered experimental settings or outdoors in fair weather, it failed miserably when subjected to real-world operational demands, such as temperature changes, high winds, or ice storms. The Magnetic and its contemporaries soon discovered that manufacturers simply lacked the technical capabilities to make copper wire strong enough for outdoor overhead lines.¹³ So-called “soft” copper soon wreaked telegraphic havoc. It stretched in warm weather, crossing wires and garbling messages. Even worse, wires haphazardly strung across railroad tracks “not infrequently dropped in the way of passing trains,” causing death and serious injury.¹⁴

Limited electrical knowledge caused further disruptions. Given a general belief “that a curving wire might affect the destination of messages, wires were drawn taut.”¹⁵ That practice stretched wires further in hot weather and snapped them in cold. One firm found its “copper wire broke as often as twice a day,” and during a single winter storm, another’s tight-drawn copper wire broke in a hundred places.¹⁶ Copper’s fragility taxed telegraph investors, rendering lines inoperable or gobbling revenue for repairs. Some firms resold the copper, while others mounted salvage efforts. The Magnetic tried twisting two copper strands together to form a single stronger wire, “but every high wind broke them.”¹⁷ In 1846, freezing rain delivered soft copper’s death blow. As icicles dangled from the Magnetic’s lines, “the wind stiffened . . . and forty miles of wire went down as by a breath.”¹⁸ With all its income devoted to repair, the firm could pay no dividend.¹⁹ Telegraphers continued to use soft copper to wind electromagnets or to connect batteries and instruments but abandoned it for overhead lines.

Through sheer happenstance, the Magnetic’s operators in Philadelphia had already learned that iron wire would conduct electricity. Finding a break in their newly built line and having no spare copper, they scrounged some iron wire from a local tinsmith, apprehensively made repairs, and were “overjoyed to find the line at work.”²⁰

They had no idea why the iron wire worked, as the answer depended on technical details they had not yet learned. In fact copper does conduct electricity better than most metals, because its internal chemical structure creates less resistance to electricity’s flow. A larger-diameter iron wire can

13. Schwantes, *Vision & Enterprise*, 39; “The Evolution of Telephone Cable.”

14. Reid, *The Telegraph in America*, 358.

15. Thompson, *Wiring a Continent*, 78.

16. Brooks, “Insulating Overhead Wires,” 186; Reid, *The Telegraph in America*, 157.

17. “Magnetic Articles,” 82.

18. Reid, *The Telegraph in America*, 121.

19. “Magnetic Articles,” 227.

20. Reid, *The Telegraph in America*, 122.

compensate for iron's relatively greater resistance, though, at least sufficiently for low-voltage telegraph use. At the time, certain European telegraphs had already used iron, but that news had been slow in reaching Philadelphia.

Iron wire soon became the telegraph's mainstay for overhead lines, but it quickly revealed many challenges of its own.²¹ Foremost among these were supply constraints, variable quality, vulnerability to rust, and maximum lengths far too short for telegraphy's needs. Wire's limited uses in the 1840s meant that little ready inventory awaited telegraph orders. Its current ubiquity in myriad applications—from electrical conductors or suspension bridges to mattress springs or trash-bag ties—helps obscure its sparing use for most of its long history. Yet many now-familiar uses only emerged after the mid-nineteenth century, including wire nails, bale ties, barbed wire, telephone wire, screw stock, coiled springs, or woven fence.²² Earlier uses of wire tended to be smaller-scale and artisanal, as in antiquity when artisans handcrafted small amounts of wire for ornament, weapons, or armor. By the early Renaissance, Europeans used primitive wire-making machines, mainly for music strings. Eighteenth-century piano makers also used iron wire, but with its “feeble tenacity . . . it was easy to break the treble strings and force a piano out of tune.”²³ That inherent weakness long confined most demand to smaller items such as pins, fish hooks, or bonnet wire.

Certain late-eighteenth-century British inventions, however, simultaneously reduced iron's cost and increased its strength. First, England's Henry Cort lowered iron's cost with the refining technique called “puddling.” He then patented a grooved rolling machine that simplified making “wire rods” that were stretched or “drawn” to form wire.²⁴ Moreover, Cort's rolling process structurally strengthened iron rods, imparting a fibrous quality that altered the metal's inherent crystalline fracture pattern. This change reduced iron wire's brittleness and increased its possible uses.²⁵

Cort's innovations helped position British wire makers to meet growing demand from early-nineteenth-century textile factories, but total US wire demand remained so minimal that US manufacturers found little incentive to invest. In 1810 annual US wire imports totaled about twenty-five tons worth \$40,000, primarily for making “cards” used in mechanized tex-

21. The author uses the general terms “challenges,” “obstacles,” or “deficiencies,” even though some wire problems resembled “reverse salients,” a military term Hughes used as a metaphor for technical problems that must be solved to prevent failure of an entire technological system. Reverse salient connotes a sense of deviation from a generally orderly advance that simply was not the case for the early telegraph lines, which simultaneously struggled with wires, poles, insulators, management, and operations. See Hughes, *Networks of Power*, 79.

22. Wright, *Wire Technology*, 10.

23. Hipkins, *History of the Pianoforte*, 10.

24. Swank, *History of the Manufacture of Iron*, 53–54.

25. Sexton, *An Elementary Text-Book of Metallurgy*, 106.

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tile mills.²⁶ Wire's exemption from US metal duties also encouraged imports; further, "the English wire drawers became the best in the world, particularly because they had available extremely high-quality iron billets imported from Sweden."²⁷ Nevertheless, English wire considered exceptional for a textile card's short teeth would seem less exceptional at mid-century, when telegraph builders needed high-quality, rust-resistant wire in unprecedented continuous lengths.

US iron manufacturing's emphasis on railroads also constrained US wire production, even as telegraph demand increased. Given a choice between rolling iron rails for burgeoning railroads or rolling wire rods for the telegraph—a newer technology with an uncertain future and far less demand than railroads—few mills chose wire rods. By 1852 US telegraph wires totaled more than 24,000 miles, which initially sounds impressive but amounted to less than four thousand gross tons in total, or less than one-half of 1 percent of total US iron production, and equivalent to about fifty railroad miles.²⁸ Most iron mills therefore remained focused on rails: in 1859, after fourteen years of commercial telegraphy, only nine of two hundred US mills made wire or wire rods.²⁹

The few US manufacturers who did want to make wire found few skilled US wire-rod rollers or wiredrawers. US immigration policy nonetheless helped attract skilled immigrants, including experienced European wiredrawers. The United States encouraged "foreign artists and tradesmen . . . to settle in the country. The implements, tools, and even the furniture of emigrant mechanics, were made free of duty," and individual states added further incentives: Pennsylvania gave mechanics the special privileges of "freeholders on the day of their arrival, provided they declared their intention of becoming citizens within the time prescribed by law."³⁰ More than 452,000 mechanics, miners, engineers, or manufacturers immigrated to the United States from 1820 through 1860.³¹

Of these, British and German immigrants especially influenced the US wire industry. Rather than importing British wire, some New Englanders hired skilled English craftsmen to build or staff wire mills.³² In 1836, when Anson Phelps and his associates founded the mill that became Ansonia

26. Gallatin, "Report of the Secretary of the Treasury on Manufactures," 186.

27. Sayenga, "Essay on Wire Bridges," 10.

28. Wire and rail weight varied; this assumes 300 pounds per mile for wire and 50 pounds per yard for rails. Iron production for 1852 estimated by averaging data for 1850 and 1854 given in *Annual Statistical Report of the American Iron and Steel Association* (1897), 59.

29. Lesley, *The Iron Manufacturer's Guide to the Furnaces, Forges and Rolling Mills of the United States*, 219–62.

30. Both quotations from Scrivenor, *History of the Iron Trade, From the Earliest Records to the Present Period*, 208.

31. North and Thomas, *The Growth of the American Economy to 1860*, 233.

32. Sayenga, "Essay on Wire Bridges," 10.

Brass and Copper, they brought both workers and machinery from England.³³ Stevens & Thomas, which made wire for Morse's government line, also employed English craftsmen.³⁴ John Roebling, a German engineer who immigrated to Pennsylvania, made wire rope for heavy hauling and later for suspension bridges. By century's end, the company Roebling founded in New Jersey also became a major supplier of electrical wire.

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Most developments detailed in this study, however, center on the Worcester, Massachusetts firm best known as Washburn & Moen Manufacturing Company ("Washburn"). Washburn illustrates important aspects of conducting wire's history; it frequently implemented both European and American inventions and thus offers insight into the international industry's overall progress. Much of the firm's success stemmed from the innovative vision of Ichabod Washburn, who served a blacksmith's apprenticeship before he and partner Benjamin Goddard began to draw textile-card wire in 1831. In 1847, the firm built a new mill of British design and began making telegraph wire.³⁵ Yet, at that time, even the most diligent wire makers lacked control over their product's quality, and even the most-experienced wiredrawers lacked materials and machines that could overcome wire's principal challenges.

In 1848 the Magnetic's then-president, Benjamin French, reluctantly advised the stockholders that much of the firm's new iron wire was "not of so good a quality as it ought to have been." Informal "inspection" had inadvertently examined only the best of the lot and much wire had already been strung. With no other ready supply, French decided "to take the wire as it was, and do with it as we best could," although it would have to be replaced at further cost.³⁶ Doing "as we best could" largely meant cutting out the worst sections, splicing the rest together, and hoping for the best. Moreover, French's contemporaries shared his dilemma. By 1852 wire's deficiencies had already forced most firms to rebuild their lines—in many cases, multiple times—and dismayed investors repeatedly saw their firms scrap costly but useless wire.

The numerous steps involved in wiremaking left the final manufacturer with little control over quality. Wire production encompassed mining, refining, rod rolling, and wiredrawing; variables introduced at any stage could compromise finished quality, and even slight ore variations could weaken wire. By century's end, wire makers would implement rigorous testing against published standards, but in the interim they struggled with quality—and telegraphers suffered the consequences.

In 1854 *Shaffner's Telegraph Companion* summed up wire's inconsistencies: "We have seen all qualities used. Some worthless, and some very

33. *Metal Industry*, 20, No. 8:299.

34. Shaw, *History of Essex and Hudson Counties, New Jersey*, 890-f.

35. *Inland Massachusetts Illustrated*, 38–40.

36. "Magnetic Articles," 83.

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superior.”³⁷ With neither standards nor controls to ensure quality, the telegraph’s pioneers literally paid their money and took their chances. Moreover, even telegraphers fortunate enough to obtain “superior” iron wire still wrestled with rust, which could inhibit electrical flow and destroy the wire itself. Until manufacturers devised effective countermeasures, telegraphers improvised against rust as best they could. Some applied tar to form a simple barrier.³⁸ On one 1840s line, that onerous task fell to “a newly-landed Scotchman . . . with a tar bucket slung to his side, and a monster sponge in his hand.” An eyewitness reported the hapless man succumbed to his ordeal: “Tar proved too much for him. He went to sleep and never woke,” and his fellow workers buried him where he lay.³⁹

The 1850s telegraph community circulated other possible remedies, such as using wire “covered with cotton or wool, and then varnished with pitch or asphaltum, dissolved in coal naphtha or marine glue, and renewed by some arrangement every six months.”⁴⁰ Similar ideas came and went, but none offered a workable solution. Rust proved especially disastrous when builders tried to strengthen lines by using multistrand iron cord. Its twists held moisture, and rust-eaten cord that broke under tension unfurled violently and erratically. Near railroads it “would curl up wildly and become entangled in the wheels of passing trains,” sometimes thrashing with enough force to saw into wooden cars. Telegraph pioneer James Reid called multistrand cord “one of the most unfortunate inventions of an era when invention was prolific of many unfortunate things.”⁴¹

The most promising rust solution involved coating iron wire with molten zinc—in a word, galvanizing—which inventors patented in France, the United States, and Great Britain during the 1830s.⁴² The zinc itself oxidized but formed a “sacrificial” barrier that protected the underlying iron.⁴³ Still, galvanizing offered no miracle cure. Polluted or salt-laden air destroyed the zinc; in some British manufacturing towns wire crumbled under its own weight from “destruction of the zinc by gradual deposit and decay.”⁴⁴ Moreover, large-scale wire galvanizing posed practical challenges. Britain’s George Bedson obtained a US patent for his process in 1863, but wire makers found it difficult.⁴⁵ In principle, galvanizing involved a few simple components: an acid-bath tank, a vat of molten zinc, and mechanisms to convey the wire through both. In practice, the acid

37. Shaffner, *Shaffner’s Telegraph Companion*, 1854, 1:50.

38. Sayenga, “Essay on Wire Bridges,” 14.

39. Reid, *The Telegraph in America*, 122–23.

40. Turnbull, *Lectures on the Telegraph*, 179–81.

41. Reid, *The Telegraph in America*, 160, 408.

42. “History of Galvanizing.”

43. Sayenga, “Essay on Wire Bridges,” 14.

44. Shaffner, *Shaffner’s Telegraph Companion*, 1855, 2:194.

45. Sayenga, “Essay on Wire Bridges,” 14, citing US Patent 37,669, dated 17 February 1863.

emitted toxic fumes, expensive vats ruptured and spewed costly molten zinc, and wire splices routinely jammed the equipment, bringing the entire process to a standstill. Washburn first tried to circumvent galvanizing by boiling wire in oil. It later adopted a crude galvanizing process: “dipping the coils of wire in molten zinc, after which the surplus metal was shaken off by violent pounding.”⁴⁶ Edwin Hill of Worcester assigned galvanizing patents to Washburn in 1872, and by 1882 Western Electric’s supply catalog emphasized the high quality of Washburn’s galvanized wire.⁴⁷ By 1910 nearly fifty US patents had overcome wire galvanizing’s main challenges.

Consequently, by the time Bell introduced local telephone service in 1878, Washburn had already incorporated more than three decades of international experience in its galvanized wire. Western Electric’s 1882 supply catalog, which exclusively offered Washburn wire, noted that “for telephone construction . . . galvanizing is of great importance, as the life of the wire depends almost entirely on it.”⁴⁸ This means that telephone promoters largely avoided the rusty wire that pained first-generation telegraphers—offering just one of many examples that the network’s material continuities transcended applications and that industrial context shaped network infrastructure, for better or for worse.

Unfortunately, a challenge even more pressing than rust long preoccupied most wire makers. At midcentury, the longest continuous wires either Europeans or Americans could make were simply too short for the telegraph’s needs, and that deficiency prompted most patents in this study. Short wires increased the number of splices or joints each line required, and each splice created a potential failure point, whether structural or electrical, for the entire line. Yet wire making’s limitations meant each telegraph wire could need twenty-five splices per mile; needed lengths required major mechanical and material changes not fully developed until the early-twentieth century. Splicing might now sound utterly mundane, but “joints carelessly or ignorantly made” routinely degraded or stopped electrical flow.⁴⁹ Splices weakened lines under tension, trapped moisture, and increased electrical resistance, but for years telegraphers had no standard technique.⁵⁰

Primitive repair practices made matters worse. To locate faults, line workers cut the wire at intervals, checked for current with a portable telegraph key—or, sometimes, by touching the wire to the tongue—then spliced the line back together. This practice created a vicious cycle of further failures at the many “imperfect joints made in the process of repairs.”⁵¹ Yet

46. Washburn, *Industrial Worcester*, 146.

47. Hill, Improvement in annealing and tinning wire; Hill, Improvement in apparatus for annealing and tinning wire.

48. “Western Electric Company,” 17–18.

49. Reid, *The Telegraph in America*, 127.

50. Sayenga, “Wrought-Iron Wire Cables,” 52.

51. Reid, *The Telegraph in America*, 648.

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even in 1860, a respected line superintendent's handbook provided no specific guidance, saying only that upon locating a broken wire "a piece of wire is joined to the longer part sufficient to reach to the next pole. The repairer then . . . mounts the pole, taking the wire in his hand . . . [and] joins the wire."⁵²

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Finally, an 1869 handbook by Franklin Pope, who later helped found the American Institute of Electrical Engineers, emphasized that a circuit's continuity or flow depended on "the perfection of the joints." He said a rusty, unsoldered splice added more resistance—which US telegraphers had just learned to measure—than fifty miles of line, and he recommended a technique called the Western Union/Lineman Splice (fig. 1).⁵³ Notably, this technique represented the culmination of a quarter-century's collective line building and maintenance experience; by 1869 inventors had also begun to patent sleeves, couplers, or other specialized hardware to simplify splicing.

The larger point is that Pope codified this best practice just as William Orton, then Western Union's president, began to rebuild that firm's agglomerated network in the late 1860s, an undertaking historians rank among his most-important achievements. True, as Richard John said, Orton "consolidated the rickety telegraph network that his predecessors had built," but what typically goes unnoticed or unremarked is that Orton benefited from material changes and accumulated experience unavailable to his predecessors. Moreover, Orton enjoyed those benefits largely thanks to his predecessors' efforts. Despite Orton's laudable managerial prescience, therefore, attributing Western Union's technical improvements primarily to his personal qualities overlooks the substantially different material environment in which he operated compared with his predecessors.

In this study, industrial context shifts the focus from the rickety state of pioneer lines to the ways in which pioneer experience catalyzed changes beneficial for Orton and other later entrants. This in no way suggests that Western Union played little part in the wire industry's development; undoubtedly, the presence of a single large customer embarking on a well-publicized multiyear rebuilding program provided substantial incentives for manufacturers to address its needs. Nevertheless, pre-consolidation telegraph companies bore many direct costs of the network's growing pains, suffering what business theorists call a "first-mover disadvantage." Followers typically enjoy enduring advantages over pioneers, because they learn "from the mistakes and successes of their predecessors, reducing their own investment requirements as well as their risks. In addition, fol-

52. Prescott, *History, Theory, and Practice of the Electric Telegraph*, 283.

53. Pope, *Modern Practice of the Electric Telegraph: A Handbook for Electricians and Operators*, 90–91. In 2016, NASA's wiring workmanship standard still used the "Western Union" splice to illustrate good practice; see "Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring," 71. The British settled on another splice called the Britannia.

lowers can frequently adopt new and more efficient processes and technologies” that incorporate the lessons learned from pioneer experience.⁵⁴

Conservative estimates show substantial aggregate spending on telegraph wire by 1850: the Magnetic alone spent at least \$21,000 between 1847 and 1850 replacing wire—more than its initial stock subscription for the entire line and equivalent to nearly \$700,000 in 2018 dollars.⁵⁵ Reid’s memoir lists about thirty early companies with similar line-building experiences; assuming even half incurred wire costs comparable to the Magnetic’s, pioneer firms collectively spent at least \$315,000 (more than \$10 million in 2018 dollars) to replace deficient wire in the telegraph’s first few years.⁵⁶ For comparison, a \$100,000 investment taxed Bell’s main backers as they commercialized the telephone thirty years later, according to Christopher Beauchamp.⁵⁷ In other words, telegraph pioneers paid a substantial first-mover penalty that gave Orton, the Bell companies, the Edison companies, and many others materially better starting positions and enduring cost advantages.

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Inventing Solutions

More than five hundred US patents issued between 1860 and 1910 provide evidence of telegraph-catalyzed changes related to bare conducting wire. Almost 90 percent date from 1880 or later, or at least thirty-five years after pioneers began building lines (fig. 2). Given wire’s known challenges before then, this delay requires investigation.

US industrial historian Albert Bolles noted in 1881 how few improvements Americans had by then introduced for wire making relative to “every other industry.” He attributed the lag primarily to “foreign competition” coupled with wire’s previously limited uses, notwithstanding mid-century telegraph demand.⁵⁸ To put that demand in perspective, by 1880 Western Union operated 234,000 wire miles—another impressive-sounding total, but still fewer than 32,000 gross tons of wire, less than 1 percent

54. Boulding and Christen, “First-Mover Disadvantage.”

55. “Magnetic Articles,” 51, show Magnetic spent \$7,000 replacing its original copper with iron cord, an estimated \$7,000 replacing the iron cord with the “not of so good a quality as it ought to have been” iron wire, and another \$7,000 replacing that. Throughout this study, comparable values for 2018 calculated at www.measuringworth.com; this instance uses 1850 as base year and includes material cost but excludes labor.

56. See Reid, *The Telegraph in America*, table of contents. Excludes the municipal telegraphs first built in the early 1850s.

57. Beauchamp, *Invented by Law*, 52, citing Alexander Graham Bell to Gardiner Greene Hubbard, July 28, 1880, box 79, Bell Papers; Rosario Joseph Tosiello, *The Birth and Early Years of the Bell Telephone System: 1876–1880* (New York: Arno Press, 1979), 158–59, 185.

58. Bolles, *Industrial History of the United States*, 299–301.

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of total US iron production, and equivalent to about 400 railroad miles, at a time when US railroads owned 100,000 miles of road.⁵⁹ Even in 1880, therefore, telegraph-wire demand still gave most US iron mills few incentives to invest in wire making.

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US incentives changed dramatically during the 1880s, for two reasons. First, Bessemer-steel rails displaced iron rails, whose production plummeted 87 percent from 1881 to 1883, and iron mills scrambled to diversify.⁶⁰ Second, Western Union wire miles nearly tripled in the 1880s (fig. 3), while telephony and distributed electricity services had also begun to grow. Notwithstanding demand's substantial influence on overall US wire investment, patent evidence shows that making wire that met the telegraph's needs also depended on changes in materials, machines, and expertise, but many such changes developed gradually. The primary industrial functions involved in these patents help illustrate this point. More than three-fourths centered on intricate mechanical processes—gearing, driving, reeling, braking, and material-handling mechanisms (fig. 4). These processes showed strong interdependencies with industrial materials and machines that became more complex as manufacturing scale increased and thus heavily relied on developments in mechanical engineering.⁶¹

Wired infrastructure emerged during the US transition from mechanical practice centered on local machine shops to mechanical engineering dominated by academically trained professionals.⁶² Before midcentury, US mechanical practice was largely the purview of master mechanics and their apprentices in machine shops, but formal academic programs increased during the 1860s, making mechanical engineers more available to industry by the 1870s. Philanthropic industrialists furthered this shift by supporting technical institutes. In the 1860s the devoutly benevolent Ichabod Washburn funded, equipped, and staffed a machine shop for the free school that later became Worcester Polytechnic Institute (WPI). By the early 1870s Washburn's technical corps included WPI-trained engineers, including the mechanically brilliant Fred Daniels—the most prolific wire patentee in this study and, eventually, chairman of U.S. Steel's board of engineers.

The British founded a society for mechanical engineering in 1850, and prominent US machine builders created the American Society of Mechanical Engineers (ASME) in 1880.⁶³ Yet even Britain's longer wire-making his-

59. "Rail Track Mileage and Number of Class I Rail Carriers, United States, 1830-2016."

60. Misa, *A Nation of Steel*, 70; Swank, *Statistical Abstract*, 4. As Misa notes, this is the same period in which US mills began to roll structural shapes.

61. As used in this study, "interdependence" conforms with the sense advanced in Rosenberg, "Technological Interdependence in the American Economy," meaning that solutions developed for problems in one industry often solved similar problems in others.

62. For more on this phenomenon, see Calvert, *The Mechanical Engineer in America, 1830-1910*; Israel, *From Machine Shop to Industrial Laboratory*.

63. "Engineering History."

tory and its head start in professionalizing mechanical engineering gave it little overall advantage for telegraph wire. Despite the strong foreign competition Bolles noted before 1880 for telegraph wire, Europeans competed more on manufacturing capacity than superior technology. Washburn and others could and did buy European machines, and 10 percent of the US patents in this study originated with European inventors, but these still fell short of the telegraph's needs. In short, the mechanical and material improvements that eventually eliminated wire's deficiencies challenged Europeans and Americans alike.

Wire patents also show that their inventors coalesced around wire- or machine-making centers. Just five US cities—Worcester, Pittsburgh, Providence, Waterbury, and Cleveland—originated more than two-thirds of the wire patents in this study, and Worcester alone produced more than a third (fig. 5). This finding adds further dimension to previous studies that show how machine shops influenced telegraph invention. Paul Israel nicely detailed the formative influence of the Boston workshop operated by Charles Williams and frequented by both Alexander Graham Bell and Thomas Edison; Israel concluded that Boston and New York machine shops generated most telegraph inventions, but he primarily focused on instruments used to send or receive telegraph messages.⁶⁴ A network-centric perspective, in contrast, identifies other cities with substantial inventive importance for telegraphy.

The patents in this study also show considerable concentration by individuals, just five of whom produced more than 25 percent of the overall total—and Washburn's Fred Daniels patented half of those, or about 13 percent in all. None of these top five was an "independent" or lone inventor: all had connections with rod mills, wire mills, or machine-tool makers, as did many other patentees. For comparison, Bell had no wire-making patents and Edison obtained three in the 1890s for using electricity to heat rods or wire, while Daniels produced sixty-five of the patents included here.⁶⁵ These encompassed metallurgical furnaces, rod-rolling mills, wiredrawing machines, automated material handling, safety devices, and galvanizing.

Wire's Machines and Materials

Eliminating iron wire's most troublesome deficiency—shortness—required substantial mechanical and material changes. At the simplest level, wire making stretches a single metal mass into a long, thin shape; increasing wire's continuous length therefore required beginning the process

64. See Israel, *From Machine Shop to Industrial Laboratory*, chap. 4, esp. note 36 at 99.

65. US Patents 436,968; 436,969; and 563,462. Daniels had numerous additional patents beyond the sixty-five in this study, including many related to barbed wire or rail bonds.

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with a larger mass, called a “billet.” Rod-rolling mills shaped billets into coarse wire rods; wiredrawing mills then stretched or “drew” the rods through dies to form wire. Skilled rod workers manipulated the stretchy, red-hot iron mass with tongs, which effectively constrained the billet’s maximum weight. This constraint resulted in excessive splicing on telegraph lines and interrupted or degraded the network’s flow. After 1860, inventors began to address the need for longer wire with two different rod-mill types: the “continuous” mill and the Belgian or “looping” mill. Both types accommodated larger billets, and Washburn tried both.

In 1862, George Bedson built the first continuous rod-rolling mill in England, using mechanical guides to minimize manual handling and allow larger billets. Wire-industry professional Kenneth Lewis called the telegraph “the driving force behind [Bedson’s mill] and behind the whole series of attendant changes associated with heavy bundles” of longer wires.⁶⁶ Bedson made rods so long they were soon dubbed “rod coils,” and Washburn engaged Bedson to build and staff a continuous mill in Worcester.⁶⁷ Although Bedson installed Washburn’s mill in 1869 and tried to obtain a US patent for it, he was frustrated in that effort because Henry Comer of Pittsburgh had patented a similar design in 1859, even though Comer had not actually built his mill.⁶⁸

The heart of Bedson’s mill was its continuous rolling train (fig. 6), whose function heavily depended on synchronizing its eight sets of gears. Gearing mattered because the rod moved faster as it lengthened, requiring each successive set of rollers to turn more quickly to take up slack. Synchronization prevented overly fast rolling, which caused excess tension that could break a high-velocity rod and cause a dangerous “loose end or flying loop,” and it also prevented overly slow rolling that backed up the oncoming rod, causing kinks that stopped production while workers cleared “cobble” by hand.⁶⁹ Synchronizing rollers depended on accurately cutting the rolling train’s difficult bevel gears, which relied on precision metal-machining tools. Improvements in those machines enabled cutting gears accurately and in quantity; as Robert Woodbury emphasized, those same capabilities underlay mass production of such diverse products as sewing machines, bicycles, and automobiles.⁷⁰ Their importance in synchronizing rod rollers likewise highlights gearing’s little-noticed but vital importance for the wire industry and thus for wired infrastructure, highlighting its deep links with broader industrial changes.

Washburn’s new mill eventually produced 80-pound rods, which

66. Lewis, *Steel Wire in America*, 70.

67. Daniels, “Rod-Rolling Mills and Their Development in America,” 248–52.

68. Comer, *Machine for Rolling Iron*.

69. Daniels, *Guard-screen for rolling-mills*.

70. Woodbury, *History of the Gear-Cutting Machine*, 5, 77; for comparisons of British and American machine tool development, see Roe, *English and American Tool Builders*.

strained other mill components to the breaking point—a common phenomenon Rosenberg called “technological disequilibrium.”⁷¹ With the mill’s old hand-cranked take-up reels, “the labor was too exhausting, and . . . hampered the full efficiency of the continuous mill.”⁷² Reeling also caused many accidents, as the rod emerged in a “red-hot state” from the last rolls, where workers “caught” it with tongs, guided it to the reel, then coiled it by hand.⁷³

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Automatic-reeling inventions—part of wire manufacturing’s gradual move toward continuous-flow processes—represent about 20 percent of patents studied here. Charles Morgan, Washburn’s general superintendent until 1887, patented a steam-powered reel that replaced the mill’s hand cranks and an automatic-handling system that simultaneously reeled two rods and discharged the finished coils into wheeled trucks (fig. 7). Morgan, a machine-shop veteran who later served as ASME’s president, left Washburn to found Morgan Construction Company, which designed and built rod-rolling and wiredrawing mills worldwide.⁷⁴ Five successive generations of Morgans led the privately held firm until its sale to Siemens AG in 2008.⁷⁵

Washburn’s continuous mill still failed to meet the telegraph’s needs, even though augmented by a new Siemens furnace, imported Swedish iron, and power reels. The problem lay with the iron itself: Washburn used the best iron available anywhere, but it lacked the tensile strength required for continuous rod rolling. Daniels said that in the early 1870s it was “impossible to obtain iron of uniform quality, sound and homogeneous, and it was up-hill work to obtain satisfactory results” for telegraphy.⁷⁶

In a fateful decision with consequences far beyond telegraphy, Washburn decided to test Bessemer steel in its continuous mill and put Fred Daniels in charge of testing. Based on his results, Washburn adopted Bessemer steel for continuous rolling, creating “a revolution in the wire business, substituting . . . a better and cheaper material for very many purposes.”⁷⁷ Most notably, Washburn acquired patents for barbed wire and greatly expanded its fencing-wire business during the peak decades of America’s westward expansion—showing that efforts to improve telegraph wire also yielded significant spillover effects in other economic sectors. In 1882 Western Electric’s catalog offered both steel and iron wire for telegraph and telephone lines.⁷⁸ Steel’s strength also prompted new line-building techniques, such as clipping a lighter-weight copper conductor to a

71. Rosenberg, “Technological Change in the Machine Tool Industry, 1840–1910,” 440.

72. Morgan, “Some Landmarks in the History of the Rolling Mill,” 54.

73. Morgan and Daniels, *Reel for rolling-mills*.

74. Nutt, *History of Worcester and Its People*, 2:1070.

75. *Worcester Business Journal*, 7 January 2008.

76. Daniels, “Rod-Rolling Mills and Their Development in America,” 251–52.

77. Washburn, *Industrial Worcester*, 153.

78. “Western Electric Company,” 17–18.

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stronger steel “messenger” wire. Today, builders still “lash” fragile fiber-optic cables to stronger overhead suspension strands.⁷⁹ More generally, using Bessemer steel to improve telegraph and telephone lines further illustrates the network’s interdependence with far-ranging industrial changes.

As wire makers struggled with iron, overhead copper launched a serendipitous comeback in 1877, about thirty years after soft-copper wire’s demise for overhead lines. Thomas Doolittle, an enterprising employee of Ansonia Brass & Copper in Connecticut, succeeded where others had long failed and made “hard-drawn” copper wire, which doubled the copper’s strength under tension and reduced its tendency to stretch but largely maintained its conductivity.⁸⁰ Memories of overhead copper’s debacles still lingered, and telegraphers initially remained skeptical. Eventually, however, hard-drawn copper proved essential to reaping the cost-saving potential of Edison’s quadruplex, considered his “most important telegraph invention” because it simultaneously carried four messages on one wire, substantially reducing line cost.⁸¹ Electrical engineers later attributed much of the quadruplex’s success between 1885 and 1895 “to the extensive employment of hard drawn copper wire for telegraph purposes,” showing the extent to which some of the industry’s better-known inventions depended on the efforts of lesser-known inventors.⁸² The Franklin Institute awarded Doolittle its medal of merit in 1898, saying “it was due entirely to . . . [Doolittle] that hard-drawn copper wire was at length adopted for telegraph and long-distance telephone purposes” and commending his “persistent endeavors, in the face of adverse conditions,” to secure its use by electric line builders.

Although telegraphy’s needs triggered its development, hard copper substantially benefited telephone and electrical systems. Notably, Doolittle succeeded just before Bell began selling telephone service in 1878 and five years before Edison opened his Pearl Street generating station. In the 1880s, long-distance telephony used copper lines leased from telegraph firms.⁸³ In fact, the Franklin Institute attributed the success of long-distance itself “in large measure” to Doolittle’s work. Moreover, numerous letters and invoices in the Edison papers document the customer-supplier relationship between Edison and Ansonia Brass and Copper, which supplied both hard and soft copper for Edison’s Menlo Park and Pearl Street systems. Doolittle’s work on the telegraph’s behalf thus spared Bell and Edison many of the wire challenges that had vexed early telegraphers—again

79. Corning Cable Systems, “Lashed Aerial Installation of Fiber Optic Cable.”

80. Unless otherwise specified, the information about hard-drawn copper wire in this and the following two paragraphs comes from “The Introduction of Hard-Drawn Copper Wire,” 184.

81. “Quadruplex - The Edison Papers.”

82. Maver and McNicol, “American Telegraph Engineering-Notes on History and Practice,” 1311.

83. Maver and McNicol, 1323.

demonstrating the wired network's continuities and the telegraph's role in catalyzing key wire-industry developments.

At about the same time that Doolittle introduced hard-drawn copper, Washburn installed another mill better suited to rolling the available iron, the so-called "Belgian" or "looping" mill that by then was the most common type of rod-rolling mill in Europe. In contrast with continuous mills that tried to eliminate manual handling, looping-mill workers still manipulated the red-hot metal, but they managed larger billets by looping lengthening rods on an iron-plate floor. The floor helped support the heavier load, but it also reduced heat loss—an important consideration where workers continually raced against time, knowing that a delay "chills the metal and unfits it for use."⁸⁴ US looping mills underwent rapid improvements, including many patented by Daniels, Morgan, or the Scottish immigrant William Garrett, who worked with mills in Cleveland, Pittsburgh, and Chicago; he influenced them to such an extent that US looping mills became commonly known as "Garrett" mills. By 1893 two-thirds of all US-made iron wire rods came from looping mills.⁸⁵

Despite producing better wire rods, these mills routinely imperiled millhands, especially the young workers called "hooker-boys." Because kinks caused rods to buckle and flail unpredictably, most looping mills employed "very bright and active" boys who hooked the rods emerging from the rollers and raced across the mill floor, stretching the rods to prevent kinking. The inherent dangers prompted numerous safety-related patents; in the 1880s, some mills tried to replace hooker boys with inclined floors and mechanical guides, but these proved minimally effective, and the hooker-boys' plight continued into the twentieth century. In 1900 manufacturer Michael Baackes patented a "mechanical hooker-boy," noting "the rod travels with great speed, is red-hot, and the loop is liable to jump or kink." Baackes also said the young workers commanded "exceptionally large wages," for it was not unusual that one had "a leg or arm taken off by the sudden tightening of the red-hot rod's loop, and more-serious accidents" often occurred. He proposed replacing hooker-boys with sprocket-and-endless-chain mechanisms then used in applications from bicycles to industrial material handling; Henry Roberts of Pittsburgh patented a similar endless-chain arrangement to prevent rod loops from "fouling and tangling with other loops."⁸⁶ Other patentees introduced safety features such as portable guard screens and automatic braking. These inventions and the circumstances that prompted them illustrate that examining infrastructure's industrial context can link its development with social concerns such as industrial safety or other progressive-era labor issues.

84. Roberts, *Wire-rod mill*, filed April 23, 1888, and issued November 6, 1888.

85. Daniels, "Rod-Rolling Mills and Their Development in America," 302–3.

86. Baackes, *Mechanical hooker-boy for rod-mills*; Roberts, *Wire-rod mill*, filed 13 February 1900 and issued 10 July 1900.

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By 1893 the United States annually rolled more than a half-million gross tons of wire rods and had enough capacity to double production.⁸⁷ Cumulative mechanical advances had enabled wire-rod makers to reduce labor while increasing output, and US rolling mills routinely produced 150-pound iron rod coils for telegraph wire. As Washburn had found with reeling, though, changing just one of a system's parts can bring other limitations to the forefront. In this case, larger rod coils highlighted wiredrawing's constraints. Conceptually, nothing about the change from 10-pound wire rods to 150-pound rod coils altered wiredrawing's fundamentals: forcibly stretching a hot metal rod by pulling it through a die, then repeating the drawing through successively smaller dies to reach a desired cross-section. On the factory floor, though, drawing long continuous wires entailed considerable complexity.

Ichabod Washburn said in his autobiography, "The first coarse wire machine that I ever saw, was one of self-acting pinchers, drawing out about a foot, then passing back, and drawing another foot; so crude . . . was this machine that no man could draw on it more than fifty pounds a day." Washburn improved on that 1830s machine by attaching the wire to a rotating wire "drum" or "block," similar to a pulley in a block-and-tackle system. The block's rotation forcibly drew the metal through the die, replacing the mechanical "pinchers" and increasing drawing speed.⁸⁸ Otherwise, wiredrawing changed very little for several decades, except for the heavier rods. This in no way suggests that wiredrawing lacked further demands or challenges; rather, material constraints posed persistent obstacles to addressing them.

Consequently, the typical late-nineteenth-century US wiredrawing machine still operated with a single block and a single die (fig. 8). To draw wire, workers placed a heated rod coil on the supply reel (*i1*), *manually shaped the rod's point to thread it through the reducing die* (*f2*), and attached it to the drawing block (*b1*). Each rod could undergo more than a dozen subsequent reductions to reach the desired wire size, and each reduction required workers to change the die, repoint and rethread the metal, and make intermediate trips to the annealing furnace for heat. Single-die systems remained typical until after 1900, despite numerous efforts to develop multiple-die machines for continuous drawing at "one heat." In 1873, Joseph and Edwin Woods of Great Britain obtained the first US patent for a continuous, multiple-die machine (fig. 9). The inventors paired each die (*bn*) in the sequence with its own intermediate block (*cn*) to take up slack and to maintain tension as the metal stretched. Other inventors, both in Europe and America, patented similar machines in the 1880s and 1890s, but, although sound in principle, all shared serious prob-

87. Bedson, "The Manufacture of Wire and Wire Rods in the United States"; Daniels, "Rod-Rolling Mills and Their Development in America," 249.

88. Washburn, *Autobiography of Ichabod Washburn*, 46.

lems in production, mainly because material deficiencies compromised gearing.

As with continuous rod rolling, continuous wiredrawing required turning successive gears at increasingly higher speeds, because each reduction in diameter lengthened the wire more quickly. Mechanical engineers could synchronize wire-block gear trains, but deficiencies in lubricants, die materials, and rod quality prevented them from maintaining that synchronization during production. As explained by Iroquois Machine Company's chief engineer, James Horton, manufacturers found it "impossible to keep these relative speeds regulated absolutely, because of changes in the diameter of the holes in the dies due to wear and because of variation in the [rod] stock."⁸⁹ In other words, friction enlarged the die holes, the wire lengthened less than expected, the next block turned too quickly for the shorter-than-expected length, and the wire repeatedly broke from excess tension.

In principle, lubricants could reduce friction and prevent these problems, but then-typical lubricants clogged the dies, backed up the oncoming wire, and caused snarls that halted production—while the hot metal inexorably cooled. Traditional lubricants were inadequate for network-scale production, but manufacturers long lacked better alternatives. Despite oil's 1859 discovery in Pennsylvania, petroleum-based lubricants developed slowly, and modern chemical manufacturing only began after 1880.⁹⁰ In 1879 the customary wiredrawing lubricant was "a mixture of meal or flour and water," which adhered poorly, required frequent reapplications, and was "quite liable to become sour, putrefy and lose its lubricant quality," damaging both wire and machines. Adding insult to injury, the damp mixture promoted rust as it dried.⁹¹ Between 1875 and 1895, nearly thirty US patents focused on wiredrawing lubricants, but in the early 1900s, some wire makers still used white wash, which friction easily destroyed.

Overly soft die materials compounded drawing problems. Excessive die wear damaged wire or machines and turned synchronization to chaos, precluding continuous drawing through multiple dies. Numerous die patents incorporated harder materials, such as industrial diamonds or alloy steel. Yet until tungsten carbide became generally available after World War I, even alloy-steel dies had a maximum lifespan totaling about one hour of use.⁹² Mechanical and material improvements overcame most such obstacles by 1910. Redesigned drums reduced wear, cooling devices lessened heat-related die distortion, better materials improved dies or lubricants, and automatic mechanisms replenished lubricants throughout the drawing process. Together, such changes let manufacturers consistently produce manageable half-mile wire lengths in a continuous operation.

89. Horton, *Wire drawing machine*.

90. Anderson, "History of Lubricants"; Chandler, *Shaping the Industrial Century*, 4.

91. Brown, *Improvement in lubricating materials for use in wire-drawing*.

92. Lewis, *Steel Wire in America*, 78.

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Until then, wire makers mainly persevered by using enough single-die machines to meet market demand. By 1891, with Washburn's output of "telegraph and telephone wires alone aggregating in value millions of dollars annually," the firm employed 4,000 workers and was considered "much the largest wire-drawing and rod-rolling concern in the world."⁹³ By the time American Steel and Wire Company ("American") acquired Washburn in 1899, the telegraph had been a key driver of Washburn's capacity growth, manufacturing innovations, and market success for more than fifty years.⁹⁴

By 1910 Western Union and US telephone companies operated an impressive 18,000,000 total miles of iron, steel, and copper wire, while electric power or light systems, trolleys, and railways added many more.⁹⁵ A robust US electrical-wire supply industry had largely vanquished bare conducting wire's challenges for wired-network infrastructure: abundant supplies offered sufficient strength, consistent quality, reliable rust protection, and adequate length. American's 1910 electrical-conductor catalog touted the firm's extensive quality controls, including rigorous testing against published standards. Its "bare" iron telegraph wire, based on "more than half a century's experience," came "extra-galvanized" against rust with a uniform zinc coating that "would not peel or crack." The company, by then part of U.S. Steel, sold "Extra-Best-Best Washburn & Moen" telegraph-wire, made by the "improved continuous process" and packaged in half-mile lengths for easy handling using wagon-mounted reels (fig. 10).⁹⁶

It would be convenient to say these developments solved all network wire problems, but despite bare wire's importance, the network also needed insulated underwater or underground cables, anti-induction cables to minimize magnetic interference, armored cables for harsh environments, or specialized high-voltage conductors for the fledgling electrical grid. American's 1910 catalog offered 150 pages of such products that resulted from nearly 1,100 additional US patents for materials and machines needed to cover bare wires with insulation and bundle them into cables.

Ironically, of all wired-network applications, the telegraph would thereafter benefit least from the wire-industry changes in which it had been so instrumental. As figure 11 shows, between 1900 and 1910 Western Union added about 500,000 wire miles; in the same period US telephone companies added more than 14,000,000.⁹⁷ Western Union would continue to add wire miles, but far fewer than telephone systems, whose extraordinary growth in wire miles stood on the telegraph's hard-won foundation.

93. *Inland Massachusetts Illustrated*, 40.

94. "Records of American Steel and Wire."

95. *Statistical Abstract of the United States* (1946), tables 509 and 515.

96. American Steel & Wire Co., *Catalogue and Handbook of Electrical Wires and Cables*, 47.

97. *Statistical Abstract of the United States* (1946), 463, 466.

Conclusion

Together, soft copper's debacles, iron wire's deficiencies, and wire making's challenges show that, far from marching anywhere, the telegraph hobbled for decades, littering its trail with haphazardly spliced wires that snapped, crumbled, flailed, and failed. The record further shows that telegraph pioneers who repeatedly rebuilt their lines paid a substantial first-mover penalty that eased the commercial introduction of other wired-network applications. Telephone promoters could avoid the supply constraints, rusting wires, and poor splices that plagued telegraph pioneers, while hard-drawn copper's introduction spared electrical-service systems from soft copper's vexations. In other words, telegraph-driven changes expanded the "adjacent possible" for wired-network applications, to borrow complexity theorist Stuart Kauffman's term for how complex systems "increase the diversity of what can happen next."⁹⁸

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Framing the telegraph as industrially important network infrastructure compels revisiting another tenet of telegraph history, one that attributes the telegraph's significance primarily to its role as a communications tool that enabled centralized business organizations and national-scale markets.⁹⁹ That view's emphasis on the telegraph-as-application implies that the telegraph network—despite its being an expansive amalgamation of copper, iron, lead, steel, zinc, wood, glass, ceramics, concrete, and sundry other materials, as well as an incubator for essential network components—somehow remained exogenous to the industrializing US economy in a materials or manufacturing sense. In contrast, this study demonstrates that the telegraph also functioned, in significant ways long overlooked, as a driver and material beneficiary of interdependent industrial changes, and that the telegraph's material needs catalyzed, shaped, and depended on an electrical-wire industry with substantial economic importance.

Rather than subdividing wired-network history by applications, then, this work reframes the analysis and focuses first on network infrastructure itself. It then examines the network's industrial context—the historically contingent materials, manufacturing capabilities, and related expertise available to network builders—thus adding new insights and greater accuracy to the historiography of North American telegraphy.

More broadly, an industrial-context framework can be applied to other physical infrastructure. Industrial context asks what infrastructure required rather than what it enabled. This approach segments network infrastructure's often-enormous scale into manageable functional focal points—its locations, links, and flow—and couples those with questions about materials, manufacturing, and expertise to bring a measure of order to infrastruc-

98. "The Adjacent Possible."

99. See, e.g., Chandler, *The Visible Hand*, 207–8; Yates, *Control through Communication*, 1, 4, 9, 22.

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ture's notorious conceptual unruliness. In addition, this flexible framework accommodates other relevant questions, especially those regarding infrastructure's material presence, historical importance, labor implications, or environmental relationships.

As for the wired network, it has many stories to tell, and this work only begins to tell them. Fittingly, those stories must be pieced together, just as telegraphers, inventors, manufacturers, and workers created the wired network itself—weaving together fragments of knowledge and disparate parts until they formed a cohesive whole.

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