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peaks, the industry frequently suffered from overcapacity. But locomotives steadily increased in size and weight throughout the nineteenth century, with average mainline engines growing from roughly 25 tons in 1860 to 72 tons in 1900.[94] Because of such evolution in their products, builders in this industry had recurring overcapacity had to reinvest continuously simply to survive, let alone grow. The funding required for capital improvements became increasingly burdensome in the 1880s and 1890s, as locomotives grew in size, weight, and complexity. The builders required larger shops, more and bigger machine tools, and heavier cranes. As the largest firm in the industry, Baldwin generally led its competitors in plant expansions. Some of the other builders also found the money for investment. Those firms that did not—notably Taunton, Mason, and Hinkley—soon left the business.

Wide fluctuations in demand, recurring years of overcapacity, and elevated capital requirements created formidable challenges for locomotive builders from 1880 to 1900. Those companies that surmounted these problems found sales aplenty as railway demand for motive power continued its long-term climb. The number of engines in service in America doubled between 1880 and 1900.[95] In the 1880s Baldwin held 31 percent of the market, and it grew to take a 39 percent slice in the following decade.[96] Baldwin's size and its first-mover advantages seem to have made the firm unassailable.

THE INDUSTRY AT ITS HEIGHT, 1890–1907

Despite Baldwin's successes, the 1890s proved a difficult decade for all locomotive builders. With a prolonged recession following the 1893 panic, the industry's total output for the decade declined slightly compared with the 1880s. This unsettled situation gave Baldwin and its smaller competitors an extra incentive to cooperate under the ALMA rather than face the mercurial market individually. When the ALMA collusion ceased is unclear; the last known price list is dated February 1897. But its success showed many builders the value of concerted action. With little conceivable chance of improving their lot separately, the largest of Baldwin's competitors decided that their main chance lay in combination. During the great Progressive Era merger movement, most of the independents combined in 1901 to create Alco, the American Locomotive Company.[97]

A horizontal combination of locomotive builders had been under consideration since at least 1892.[98] The principals could not agree then on terms for an outright merger, so they resorted to the ALMA instead. Collusion was the next best alternative to combination in response to narrowing profit margins and mounting capital costs.[99] The consolidation movement started again in 1898, when a New England financier and industrialist, Joseph Hoadley, purchased the Rhode Island Locomotive Works.[100] Using a holding company,

the International Power Company, Hoadley then engineered Alco's formation in 1901. His associates in this venture included a New York investment banker, Pliny Fiske, and a millionaire speculator, Joseph Leiter, who three years earlier had attempted to corner the Chicago wheat market.[101]

Alco was capitalized at $50 million, and by combining ten previously independent builders, it achieved rough parity with Baldwin's productive capacity.[102] Here was a potentially formidable competitor, but Baldwin's partners declined an invitation to join the new combine.[103] Although their reasons are unknown, the partners may have understood how the nature of their business and markets would preclude a successful horizontal combination of the major locomotive builders. Unlike contemporary mergers of continuous-process manufacturers such as U.S. Steel and Pittsburgh Plate Glass, which achieved substantial savings through vertical integration, a single great locomotive combine could not achieve noteworthy economies in production, since demand was so variable and engines were built in units or small batches to custom specifications.[104] The Baldwin partners understood the limits of growth in their industry and may have foreseen that one great locomotive combine would only go the way of American Bicycle, American Shipbuilding, or any other horizontal combination based solely on achieving price dominance. Mostly dismal failures, these combines were unconcerned with, and unable to make, substantial improvements in productivity. Soon new firms entered their markets and undercut their artificially high prices.[105] One large locomotive combine would still confront plunges in demand that would greatly tax its ability to service the costs of consolidation.[106] Precisely why Baldwin's partners declined to join the Alco merger is unknown, but these speculations do not seem unwarranted.

After 1901 Baldwin's partners confronted a very different competitive situation. American locomotive production reached its all-time high in the first decade of the twentieth century, but the two oligarchs competed rather vigorously in this expanding market.[107] Their highly competitive bidding seems surprising, given that the two firms essentially constituted the industry. Most likely the dynamic pace of technical change in locomotives of the period prevented Baldwin and Alco from reaching an accord on pricing. With the carriers buying more and larger engines, both builders made substantial improvements in plant and equipment to meet the crescendo of demand in the early 1900s. Thanks to these efforts Baldwin maintained its 39 percent market share of the previous decade while Alco took 46 percent. In its best year ever, 1906, Baldwin's Broad Street factory turned out 2,666 engines—more than 8.5 locomotives each working day. To accomplish this feat the plant ran around the clock, with seventeen thousand men working the two shifts.

The partners decided, however, that even this performance was insufficient to meet Alco's competition and the railways' requirements for motive power. In

1906 Baldwin began construction of a new satellite factory in the Philadelphia suburb of Eddystone. With the new plant and its 1909 incorporation, the company increasingly took on the characteristics of a modern, twentieth-century industrial firm. Unbeknownst to Baldwin, these preparations for future growth were immediately undercut by the market it had served for almost eighty years. American railway demand for motive power had peaked in 1905.[108] Thereafter Baldwin and Alco began a long decline that accelerated in the 1920s and continued until the end of steam power. They were not alone in their troubles, as much of the capital equipment sector suffered through the 1920s and the years of national depression that followed.[109]

BALDWIN AND THE LOCOMOTIVE INDUSTRY IN THE NINETEENTH CENTURY

If Baldwin increasingly entered on hard times during and after the 1920s, until then it had enjoyed a seventy-five-year ascendancy. Examining the roots of that durable success underscores particular attributes of the firm while also delineating key differences between capital equipment builders and high-volume manufacturers. The contrasts between these two formats in turn demarcate broad and important changes in American industry and society that took place between the builders' heyday in the nineteenth century and the manufacturers' supremacy in the twentieth.

The general environment for nineteenth-century capital equipment builders held so many risks and challenges that one marvels at their mere survival, let alone their impressive success in creating the technologies of industrial society. Chief among the perils was the bucking demand cycle for expensive capital goods. Every decade saw national recessions that imperiled all locomotive builders. Despite the variability in demand, Baldwin and its competitors had to accumulate sufficient profits to make the heavy investments in plant and equipment necessary for building such complex mechanisms. Before making engines, let alone profits, the builders also had to sell their products to customers across the nation and around the world. And by the 1870s the locomotive makers had lost the design initiative in their own product lines to their customers, yet they still competed among themselves on a variety of levels.

The industry responded to such challenges with a range of policies that allowed many firms to survive, and some to prosper at times. All locomotive builders sought to yoke themselves and their operations closely to the needs of American railways. When the carriers boomed, the builders at least did all right. And when the railroads deserted the market, locomotive makers learned to act collectively, holding up prices to allow profits sufficient to survive the dry spell. To meet the railways' need for custom locomotives, the builders drew upon the extensive skills of workforces that were the chief assets of such industrial

districts as Bush Hill and Paterson. The ready availability of such skills allowed Baldwin in particular to broaden its product lines and markets. The Philadelphia builder survived market reversals and achieved its growth by fulfilling extensive demand, making engines in countless designs for customers in a variety of industries all over the world. Antithetical to the manufacturers' use of standard products to exploit intensive demand, this strategy nonetheless proved viable for almost a century, until America had evolved from an industrializing, producer-driven economy to a mature and consumer-oriented society.

Mass-production manufacturing, with its attendant revolutions in distribution and management, was taken up with fervor by American industry by the 1910s. Thereafter the capital equipment firms and their machinery-building techniques waned in importance. In the 1930s General Motors would even bring rigid standardization and manufacturing methods to the locomotive industry. That it would do so successfully would have astounded Baldwin's nineteenth-century partners. For eighty years their company's growth had been based on the strategy of building whatever the customer required. Baldwin geared its internal operations and marketing tactics entirely to that end. The character of technical change in steam locomotives explains why Baldwin was impelled to develop this capacity to meet its customers' design needs.

3

THE CHARACTER OF INNOVATION IN LOCOMOTIVE DESIGN

NINETEENTH-CENTURY COMMENTATORS AND MODERN-DAY HISTORIANS HAVE written at length about the determined efforts of railroad managers to standardize the "terminology, measurements, parts, tools, and other equipment" used on their systems during and after the Gilded Age. Alfred Chandler asserts that cooperation "to promote standardization of equipment and operating procedures" was a "central theme" of American railroading during the 1860s and 1870s.[1] The period saw interfirm agreements on such technologies as standard track gauges, car couplers, car wheel patterns, and axle dimensions that unified the hundreds of individual railroads into a national system carrying through freight and passenger traffic across a number of different lines. A chief agency in this standardizing mission was the American Railway Master Mechanics Association. Created in 1868, the Master Mechanics Association devoted most of its consultative efforts to locomotive design, use, and repair.[2] In an 1874 speech to its annual convention, the noted mechanical engineer Coleman Sellers exclaimed that "the primary object of this Association may almost be said to [be to] introduce uniformity in all parts of the great railroad system of the United States."[3]

Despite Sellers's fervor for the standardizing mission of the association, and despite the general truth of Chandler's portrait of systematization, the master mechanics themselves largely resisted extending national standards to steam locomotives. Contrast Sellers's remarks with an 1899 address to the association by Joseph Bryan, the president of the Richmond Locomotive Works. Bryan opened his speech by quoting from an English newspaper that had asserted that U.S. locomotive makers built only standard designs. In response he exclaimed, "Think of that will you! Think of that, O you master mechanics, who cudgel your brains to find new designs and who for ten years have been changing your types of engines so rapidly as to make the poor manufacturer's head swim. . . .

It sounds like a roaring farce."[4] Bryan went on to plead for standard designs, noting "what a comfort it would be to the builder to . . . build something he had seen or heard of before. What an avoidance of useless expense and the assurance of better deliveries."

Although his remarks were somewhat hyperbolic—as were Sellers's—Bryan accurately characterized the master mechanics' influence on innovation. Throughout the history of steam locomotives, standard designs largely proved an unpopular and ill-fated concept. Railway master mechanics prevented the locomotive builders from establishing national standards for use on a number of lines, and within a given road standard designs were generally short-lived at best. One key factor that allowed for diversity in locomotives was that, unlike cars, they seldom traveled beyond the tracks of their own roads. But the causes for it are rooted in larger issues, and the reasons for this constant evolution and endless variety in locomotives are worth examining in detail.

Master mechanics had a variety of motives for opposing standards and promoting diversity in locomotive design, but their main concern is simply stated. Standards blocked progress. Over the nineteenth century American railways saw astronomical growth in the volume of freight and passenger traffic moving through their lines. The railways carried that burden by achieving dynamic improvements in productivity, running more trains and especially better trains—faster, longer, and heavier than ever before.[5] Such trains required more powerful locomotives with every decade, so continuous evolution ruled locomotive design, rather than a standard, unchanging technology.[6] Design change was also fostered by railways competing among themselves for traffic, vying to offer better efficiency and productivity. Some carriers attempted to establish standard engine designs, "but in every instance these have given way to the urgency of keeping pace with other roads which have not attempted to bind themselves with the iron bands of standardization."[7]

The character of innovation in locomotive design was a crucial issue for Baldwin and the other builders and is examined here in detail. As Bryan's remarks indicate, the builders had little control over the design evolution of their major products, engines for mainline railroads. How and why did they lose the initiative in design to the master mechanics? These important questions have ramifications well beyond steam locomotives. Railway car makers, shipbuilders, machine tool firms, and most other makers of large capital goods also served customers who largely defined the pace and direction of technological change in their products. The custom character of most capital equipment marked the most crucial difference between builders and mass-production manufacturers of machinery. The continuous design evolution in heavy machinery meant that its builders had to utilize different marketing techniques, production tooling, and labor skills compared with the methods of

high-volume manufacturers. Because the sources and character of innovation in locomotive design had such vital ramifications for Baldwin's operations, the subject merits detailed consideration.

Builders such as Baldwin, however, were far from powerless on matters of design. Unlike volume manufacturers, which worked up complete product designs and then anxiously hoped for their acceptance in the marketplace, capital goods builders like Baldwin often responded to their customers' specifications in a process of design mediation between buyer and seller. Such discussions were essential to both parties, since the locomotive builder had to give tangible reality to the master mechanics' design initiatives.[8] Even in cases where the customer provided complete plans—rather than general specifications—for a new locomotive, Baldwin retained some autonomy in deciding how to build the engine. Such mediation of ends and means was a crucial attribute in Baldwin's market and business success after the Civil War. But first we must turn to the prewar period to understand how and why the locomotive builders lost the initiative in the evolution of locomotive design.

EARLY AMERICAN LOCOMOTIVE TECHNOLOGY AND THE QUESTION OF PATENTS

The earliest American locomotives were either English imports or American-built copies of English designs, such as Baldwin's *Old Ironsides*. But American engineers soon adapted these designs to suit the lightweight track, rough roadbeds, and many curves common to railways in this country. In 1832 John Jervis introduced his leading truck, which guided locomotives through curves and thereby helped prevent derailments. Jervis did not patent this important improvement, and other builders quickly copied his invention, including Matthias Baldwin.

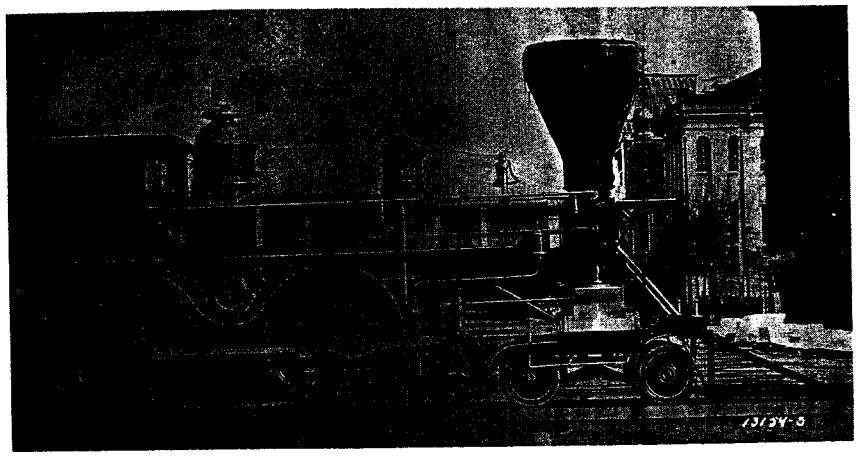
The next innovation of importance to the long-term development of locomotives sought to increase the power the cylinders transmitted to the rails. Early engines, such as that shown on page 7, had only one set of driving wheels (i.e., wheels driven by the cylinders). With heavy trains or on steep grades, these wheels would lose their traction on the rail and spin uselessly. The remedy was to add another set of drivers and connect the two sets so that the cylinders would transmit power to four points on the rails instead of just two. Henry Campbell, a Philadelphia mechanical engineer and close friend of Matthias Baldwin, patented this 4-4-0 type in 1836.[9] Such an engine is shown on page 60.

The crucial invention here was not merely the second pair of drivers; successful 4-4-0 designs also incorporated a new form of suspension, the equalizer, patented in 1838 by another Philadelphia locomotive builder, Joseph Harrison Jr., an acquaintance of Campbell's and Baldwin's. One of his patent

drawings for the equalizer is shown on page 61. Harrison's device proved very important; it allowed the transition from the early 4-2-0 type to the 4-4-0, "and few, if any, American locomotives were built without equalizers after 1840."[10]

Hindsight tells us that the American steam locomotive had acquired all its essential attributes by 1838, although further refinements continued for over a century. English contributions to the basic design included the horizontal fire-tube boiler, forced draft, semihorizontal cylinders, and power transmission from cylinders to wheels using direct connecting rods. The chief American additions were the Jervis truck and the Harrison equalizer, the latter allowing multiple driving axles. All these attributes remained in American steam locomotives until their demise in the 1950s. Significantly, of all the English and American inventors, only Campbell and Harrison patented their improvements, and they made their innovations available to all who would pay the royalties.[11] Therefore no locomotive builder controlled key patents in a way that could have prevented others from entering the field. This contributed to the competitive vitality of the antebellum locomotive industry. And the fact that no builder held an essential technological advantage in patents enhanced the master mechanics' ability to influence design matters during and after the 1850s.

This technically unfettered situation becomes apparent only with hindsight, however. The path locomotive development took during and after the 1850s was hardly discernible in the 1840s, when radically different designs competed for acceptance. Perhaps because so many basic attributes of locomotives were



Baldwin built this four-drivered engine for the Havana Bay and Matanzas Railroad early in 1861. Through driving rods the cylinders turn the front drivers, while connecting rods transmit some of this power from the front to the back drivers. This 4-4-0 was built for a Cuban line, and such exported products typically had a higher level of finish work than domestic locomotives—evident in the varnished wood cab and polished brass cylinder jackets. RAILROAD MUSEUM OF PENNSYLVANIA (PMHC)