Running the Machine: The Management of Technological Change on American Railroads, 1850-1910

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In recent years business historians and historians of science and technology have reexamined the ways big business has influenced the development of science and technology. Most have concentrated on two seminal developments. Edwin Layton, Bruce Sinclair, David Noble, and others have investigated the links businesses formed with professional, college-trained engineers around the turn of the century, while historians such as Noble, Leonard Reich, and David Hounshell and John Smith have traced the origins and functions of corporate research and development programs during the early decades of the twentieth century [1-5]. Together, this work has highlighted the importance of comprehending the goals of business in understanding engineering and corporate research and development. Engineers defined their professional mission in a manner that served the needs of particular business enterprises. Corporate research did not, contrary to some early histories of the subject, emerge simply as the outgrowth of the rise of "science-based" technology in the fields of electricity and chemistry. Rather, it developed to serve the needs of particular businesses and it assumed different forms in different business contexts.

While these historians have significantly altered our perceptions of how and why business came to manage technology, their studies leave some questions unanswered. Even as they divert attention from science to business strategy, the historians of research and development themselves continue to focus on firms in the science-based industries. Did companies outside the electrical and chemical industries pursue similar policies? If so, did their policies serve similar purposes? Studies of professional engineering do discuss engineers outside of the science-based industries, but they do so by examining the public posture engineers assumed in their engineering societies. Why did particular businesses come to place so many engineers in positions of prominence? Did they do so for reasons that apply to firms in many industries, whether science-based or not?

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The dissertation investigates these questions by examining technological innovation in the American railroad industry from 1850 to 1910.[1] By studying in detail a few significant innovations-- steel rails, braking systems, and automatic signals-- and by examining the managerial practices of four major railroads-- the Pennsylvania, the Baltimore and Ohio, the Philadelphia and Reading, and the Chicago, Burlington, and Quincy-- it suggests that railroads took a variety of steps to manage technological innovation. Drawing on the skills of professional engineers, they came to direct technical activity toward certain well-defined aims in a manner that rendered technological change routine, if not entirely predictable. Many of their efforts closely resembled those that later became common in other branches of American business, most notably the telephone and electric power industries.

Railroads developed these policies in large part because they, like companies in the telephone and electric power industries, had charge of complex technological systems. Charles E. Perkins, who served as president of the Burlington for much of the late nineteenth century, recognized the centrality of these systems when he described the task of managing a railroad as "running the machine." Perkins and his generation of railroad managers inherited complex technological systems, or machines, that had developed haphazardly during the formative period of American railroading. These systems placed enormous burdens and constraints upon Perkins and others who had charge of them. They affected all aspects of railroading, including technological innovation and its management.

The systematic nature of railroad technology mitigated against much potential innovation. Since rails, cars, locomotives, and many stationary facilities were all interconnected, altering one component could often prove more disruptive than beneficial. The narrowed opportunities for innovation greatly reduced the chances that one company would find a single innovation that would give it a significant competitive advantage. The visibility of most components of the railroad system further prevented railroads from easily monopolizing a technical innovation.

Though lacking obvious opportunities to gain significant advantage through technical innovations, railroads nevertheless felt compelled to sustain ongoing programs of technical improvement. Here, too, the nature of the system figured prominently. As Alfred Chandler has explained, railroad systems yielded significant economies of scale. Building large systems required unprecedented amounts of capital, however, and saddled railroads with large fixed costs. Railroads sought to defray these costs in two ways. First, they kept operating expenses as low as possible by pursuing what many executives referred to as "economy." Minor alterations in technology, such as the addition of a device that saved fuel, provided innumerable opportunities to reduce costs. Railroads

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[1] The remainder of this paper is based on my doctoral dissertation [6].

pursued them not so much to get ahead but to keep from falling behind. Second, railroads tried to use their capital more intensively by pushing as large a volume of traffic through the system as possible. Increasing traffic continually strained the system and together with the search for economy provided an internal dynamic that drove nearly all technical innovation in the industry.

But new technology did not provide the only avenue for handling increased volume and obtaining economy. In many cases railroads could introduce managerial innovations in lieu of technological ones. To get more freight through a tightly congested section of track, for instance, a company might just as well have altered its schedules as adopted more powerful locomotives. Railroads confronted such choices between "software" and "hardware" often as they sought to handle an ever larger volume of traffic, and over time they essentially laid down a set of ground rules: operate at slow speeds; eliminate idle time; assemble long trains and keep them loaded as fully as possible; and avoid extraordinary, one-time capital expenditures. These fundamental assumptions favored certain types of innovations while discouraging others. Two technical novelties whose primary benefit was higher speed operation (automatic signals and air brakes) became widely used only years or even decades after they became available. Meanwhile, railroads continually added cars of larger capacity, locomotives capable of getting heavier loads moving, and rails that could support these loads. Those three aspects of the railroad system posed a clearly established set of technical problems, and the industry increasingly focused its efforts at technological innovation on pushing back limits in those areas.

In pursuing organizational solutions to the problems of increased volume railroads made one other decision that had especially significant implications for their management of technological change. In order to reduce the idle time incurred while transferring goods from cars of one company to those of another, railroads agreed to interchange freight cars. In taking this step they created a situation in which companies would have to coordinate innovations involving cars. Devices such as air brakes would have to be adopted by all companies, or not at all. Because of the interconnectedness of the various elements of the system, even efforts to alter technology not directly related to cars felt the impact of this practice of interchanging freight equipment. When some companies altered the shapes of their rails, for example, they inadvertently caused car wheels belonging to other firms to wear more rapidly. Railroads who agreed to interchange equipment had to adopt a cooperative approach to many technical matters they previously had considered independently.

As the nineteenth century progressed railroads devised an array of managerial innovations that served to promote technical innovation of the fashion they desired. Within the firm, companies shifted control over technical matters from the many mechanics who worked in the multitude of shops and yards to a central staff located at the corporate office. Typically, these administrators first pressed for company-wide standardization, which itself often resulted in significant economies. Once a company had standardized its technology, moreover, it could identify specific technical problems and address them in a systematic manner, then alter technology throughout the company if needed. As part of this effort railroads beginning with the Pennsylvania in 1875 created formal laboratories and departments of mechanical engineering. They staffed these institutions with Ph.D. chemists and college-trained mechanical engineers who conducted on-going investigations of all materials used by the industry. Drafting departments, established initially at most companies to assist these research efforts, evolved into storehouses of technical information. New technology increasingly flowed out from these offices rather than up from the shops, and often it took the form of minor refinements that yielded substantial savings when spread throughout the system.

Railroads also collaborated to form institutions that functioned in similar fashion at the interfirm level. Most firms joined a variety of trade associations, such as the Master Car-Builders Association, which set industry-wide standards for many devices. Questions about railroad technology also dominated much of the work of professional engineering societies, such as the American Society of Civil Engineers and the American Society of Mechanical Engineers, which found in the standards-setting process a reason for existence. These organizations drew together experts not only from the railroads but from steel companies and other suppliers of railroad technology. By turning to these associations railroads replaced an informal, personal approach that had relied largely on the market to select appropriate technologies with a coordinated, planned approach that depended more on systematic study and consensus of experts.

As part of this reorientation railroads devised new patent policies. By assigning ownership of technical innovation to individuals, the patent system threatened to interfere with the railroads cooperative approach. This threat became apparent during the 1860s when speculative holders of patents sued railroads for using innovations railroads had considered generic. Companies responded by entering into formal patent pooling arrangements and founding organizations that coordinated their legal defenses in infringement cases. Individual firms took greater care to secure patents on all refinements to railroad technology, no matter how minor, then contributed their rights to the pools. As a result most innovation acquired an anonymous character, the apparent product of a sustained effort by a widely dispersed but centrally coordinated team of technical experts.

College-trained engineers figured prominently in all of the methods railroads introduced to manage technology. Companies that had once relied on mechanics, who had typically distinguished themselves through mechanical ingenuity and inventiveness, found these people of little value in the railroad industry of the late nineteenth century. Academically-trained engineers brought a very different set of qualities: knowledge of the scientific method, facility with statistics, and a commitment to systematic analysis. Taught to define problems carefully and proceed logically and systematically to optimal solutions, engineers met perfectly the expectations of the railroads. They functioned without frustration in an environment that often saw more value in standardizing existing technology than in introducing novelties. Unlike many mechanics, moreover, engineers could see both software and hardware as valid solutions to the problem of moving more volume through the system. Many companies, in fact, kept engineering graduates employed in the laboratory only long enough to gain familiarity with railroad problems then transferred the new recruits to managerial positions in areas such as the traffic department, where they could apply engineering methods to other aspects of the business. Finally, engineers brought to the railroads a commitment to analysis by experts rather than a reliance on the market. Pioneers among engineers and scientists who joined the railroads, such as Dr. Charles Benjamin Dudley of the Pennsylvania Railroad, advanced a vision of innovation that openly called for negotiation among experts to replace the imperfections of market transactions. Dudley and others like him found considerable support in the American Society for Testing Materials and other engineering organizations of the day.

Perhaps no aspect of railroad technology better reflected the trends described above than the ongoing efforts of railroads to obtain rails that could stand up to the steadily increasing weight of locomotives and trains. Companies addressed this problem in two stages. Between 1860 and 1880 they substituted steel for iron rails. Railroads took this step independently from one another. They considered offers from several producers, both domestic and foreign, and selected rails as they deemed appropriate. Open market transactions, conducted by top executives who lacked intimate knowledge of the technology, governed the course of innovation (though railroad investment in the steel industry did skew these transactions in some cases).

The substitution of steel for iron did not, however, cure the railroads of their problems with rails. Under the mounting strains of heavier trains steel rails broke and wore out rapidly, and by the 1870s railroads had embarked on an effort to obtain more durable rails. This second stage assumed a much different character than the initial conversion to steel. Chemists working for the railroads set out to determine the proper formula for steel rails, while the mechanical engineers used special equipment to analyze which types of steel and which shapes of rails provided the greatest strength and durability. These experts presented their results to the engineering societies, where they discussed the issues with experts from the steel manufacturers. The American Society of Civil Engineers coordinated an industry-wide survey of rail wear, then attempted to correlate wear with methods of manufacture. Many railroads sent engineers to the steel mills to observe manufacturing processes. Eventually, national associations issued standards for rails that considered an array of variables agreed upon by both producers and consumers. Railroads still placed orders with producers of their choice, of course, but the technical problems worked out in concert by experts figured prominently in their negotiations. When railroads wanted heavier rails or ones of a novel shape they turned first to the standards-setting organizations for guidance.

Over the course of the late nineteenth century, innovation in rail technology had acquired characteristics typical of much technical innovation of the twentieth century. Directed at certain well-defined aims, addressed systematically by engineers trained in the scientific method, pursued by both producers and consumers, the effort foreshadowed an approach to innovation that would soon become familiar in many branches of industry. Without significant change in theoretical understanding or science, railroads had ushered in a new age of technological innovation.

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