The Mechanization of Urban Transit in the United States

Electricity and Its Competitors

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Introduction

The industrial revolutions of the nineteenth century encouraged rapid urbanization and the widespread use of mechanical power. Central to these industrial revolutions was improved transportation between cities.[1] The application of steam power to land transportation in the form of the railroad helped accelerate urbanization and industrialization. For transportation within cities, however, horses remained the dominant motive power until the last decade of the nineteenth century. By encouraging urbanization, intercity steam railroads increased the demand for intracity transportation. This demand was met by a massive application of animal power, made more efficient by the use of streetcars drawn along iron rails laid flush to the street. Despite numerous attempts to introduce mechanical transportation in urban streets, horses remained the dominant motive power for urban transit until the adoption of the electric streetcar in the 1890s.[2]

During the last quarter of the nineteenth century, three principal technologies competed to mechanize urban street transit in the United States: steam, cable, and electricity. These technologies competed with each other, with the existing horse-drawn streetcars, and with a variety of less-developed alternatives. Electricity proved the ultimate victor, not just for street railroads but also for subways, elevateds, and many commuter railroads.

Although electricity ultimately proved cheaper than all alternatives in terms of costs per passenger mile, comparative costs do not provide a sufficient historical explanation for the success of electric traction. Reliable comparisons of the actual costs of competing systems were almost unknown, especially comparisons that accounted fully for capital costs and depreciation. Predictions of future costs of competing technologies were even more uncertain. The advantages of electric traction were established only after the inventors and engineers had devoted substantial resources to its development, and after street-railroad companies had made substantial investments in electrically powered systems.

Two factors help explain this substantial investment in electric traction despite the uncertainty in comparative costs. First was the substantial enthusiasm that Americans had for the new electrical technologies, an enthusiasm that gripped profit-minded street-railroad entrepreneurs as well as the general public. In addition, electric traction also benefited from the structure of the emerging electrical equipment industry, which supported the development of the electric streetcar in part to improve the profitability of electric lighting systems by providing a daytime load.[3]

Costs and Technical Choice

Naive theories of technical change treat the choice among competing technologies as simply a matter of costs. Business firms in a capitalist economy supposedly select, from a set of functionally equivalent alternatives, the methods that give them the lowest total factor costs. The existing state of technical knowledge defines this set of methods. Few historians and economists still accept this analysis, because it treats technical knowledge as an exogenous factor rather than as an integral part of the economy. However, when one attempts to consider the effect of the market on the creation of technical knowledge, costs no longer appear to be so decisive.[4] The success of a particular technology depends substantially on the ability of its promoters to mobilize support at early stages of its development, when costs are still uncertain. For emerging technologies, expectations of costs may be as important in garnering support as actual costs.[5] Although these expectations are in part based on extrapolations from physical theory and past experience, they remain highly speculative, and depend upon unexamined assumptions grounded in contemporary technical culture. Thus in choosing among new technologies, a whole range of cultural factors inevitably play a role, including professional ideologies, aesthetic values, and class prejudices.

Several factors conspire to make it difficult to predict costs in emerging technologies. The first set of uncertainties emerge in development, the process that transforms an invention into a working prototype, making the inventive idea progressively more concrete in conditions gradually approaching those of actual use.[6] In the process, an originally elegant invention often becomes encumbered with auxiliary components that increase its cost and reduce its effectiveness.[7] Despite the attempts of corporate managers to make the inventive process routine, the cost and performance of a new technology remain difficult to predict, given the compromises between price and performance that invariably occur during development.

Even after development is substantially complete, and the new technology is ready to be introduced into actual conditions of use, the cost of the technology remains uncertain. One set of factors tends to raise costs. In new technologies, the actual conditions of use invariably differ from those envisioned by the inventor, preventing the technology from operating as predicted. Even when conditions of use accurately reflect the inventor's expectations, dozens of unanticipated problems emerge. Inventors simply cannot afford the extensive, large-scale testing necessary to eliminate the host of minor problems that prevent new technologies from working dependably. The early users of an emerging technology also serve as testers, helping the manufacturer refine the design as components fail or wear faster than expected. Software developers use "beta" tests to formalize the role of users as testers, but informal beta testing occurs with all complex technologies. Finally, the depreciation rate of a new technology remains shrouded in mystery. Depreciation rates are always somewhat arbitrary. Users of mechanical technologies face gradually rising maintenance costs as their equipment ages. Eventually, it becomes less expensive to purchase new equipment instead of continuing to repair the old. The period may last three years or thirty, but users have no reliable means for predicting the real depreciation rate until they have gained substantial experience with the new technology.

While unforeseen problems tend to raise the costs of an emerging technology, other factors invariably work to lower costs. These factors include learning curve effects, economies of scale, and the concentration of inventive effort. Learning curve effects are perhaps the most important. Stated simply, the learning curve refers to the observation that the longer one does something, the better one gets at it. Economists first quantified this effect in the late 1930s, when they noticed that the cost of building airframes declined with the number produced, even though there was little change in technology, capital investment, or rate of production. In mechanical devices like streetcars, not only does accumulated experience in production tend to reduce the manufacturer's cost, but accumulated experience in use tends to reduce operating costs, as users refine operating strategies and improve maintenance procedures.[8] Economies of scale provide the second factor tending to lower costs. Both technical and market factors tend to reduce the unit costs of most complex technologies as rate of production or scale of application increases. Finally, the problems that emerge in the early applications of a new technology serve to focus inventive activity on that problem. In the terminology of Thomas P. Hughes, such problems identify reverse salients, weak components holding back the growth of an expanding technical system. As the technical community becomes aware of a reverse salient, its members focus inventive effort on solving the problems that create it. This mobilization of inventive effort can produce substantial savings for subsequent users.

These various sources of uncertainty make the cost of a new technology an imperfect measure of its competitiveness. Predictions of costs made during the development stage are unreliable, if only because proponents of a new technology typically underestimate costs in order to garner the necessary resources for its development. When a new technology is put into use, one set of factors tends to raise costs while another lowers them. The decision to invest in an emerging technology must therefore depend on expectations of future costs, rather than on present costs. But the benefits of scale economies and the learning curve can only be realized when investment in a new technology continues despite initial problems. Thus expectations for the success of a particular technology tend to become self-fulfilling.[9]

In a capitalist economy, where entrepreneurs obsessively discuss, dispute, and debate costs, costs do not serve as an objective determinant of technical choice. But costs still remain central. Costs provide data, but these data require interpretation before they can serve as a basis for technical choice. How costs are interpreted depends on the broader culture, including popular prejudices, utopian expectations, and general enthusiasm regarding various technologies.

The mechanization of street railroads provides an excellent example of both the centrality and indeterminacy of costs. Historians agree on the broad outline of the story, which includes the attempts to implement steam and cable systems before the final success of electricity. When it comes to the role of costs, the story is less clear.

The Evolution of Motive Power on Street Railroads

Soon after street railroads became widespread in the United States, proponents of mechanization began to criticize animal traction as expensive and inefficient. Nevertheless, urban horse railroads proved surprisingly competitive against mechanical alternatives for three decades. A few street railroads began using steam-powered streetcars during the Civil War, but the vast majority remained with horses. In the 1880s, most large American cities adopted cable systems, in which streetcars were propelled by moving underground cables driven by stationary steam engines. The huge initial cost of cable systems made them suitable for only the most dense urban areas, and horse railroads continued to dominate route mileage and passenger volume. Beginning in 1884, some cities began installing electric streetcar systems. All of these early systems proved failures, and many were replaced by cable cars. About 1888, however, the tide turned decisively in favor of electric traction. Electricity became the technology of choice for new street railroads, and existing horse railroads began converting to electricity in rapidly increasing numbers. By 1900, electricity powered almost all travel within American cities, except for walking.[10]

The earliest horse-drawn railroads, originally known as tramways, originated in mining before the development of the steam locomotive. The combination of a wheel with a rigid rail substantially reduced friction, thus increasing the load that a horse could pull over level ground. Urban tramways in the United States emerged with the first steam railroads, which were almost invariably refused permission to run steam locomotives in built-up urban areas. Beginning in the 1830s, steam railroads often continued their lines into central cities along existing streets, using horses instead of locomotives to draw the cars.[11]

These horse-drawn extensions of steam railroads spread little before the 1850s, in part because the raised "T" rail interfered with other street traffic. This problem was reduced in the 1850s by the use of grooved rails that lay flush with the street. Horsecars proliferated in the 1850s, so that by the Civil War most major American cities had significant street-railway systems. The street railroads soon drove the competing horse-drawn omnibuses from city streets, since a streetcar horse could pull twice the weight of an omnibus horse. Europeans, who lagged behind the United States in adopting urban tramways, praised the comfort and convenience of American streetcars.[12] By 1880, there were over 2050 miles of horsedrawn street railroads in American cities.[13]

American street railroads had been widespread for barely a decade before proponents of mechanization began to criticize animal power as expensive, unreliable, and unsanitary. These criticisms mounted in the 1870s and 1880s, but failed to convince streetcar companies to abandon horses and mules. Critics perceived animal power as expensive because the maintenance of horses comprised from one-third to one-half the operating costs of a street railroad.[14] Proponents of mechanization also branded as cruel the heavy work required of streetcar horses, and criticized horse droppings as a menace to public health. Horses were subject to infectious diseases that spread quickly in densely populated stables, at times paralyzing entire cities. Supporters of mechanical traction argued that it would eliminate all the drawbacks of animal power. According to one authority on street railroads, "the employment of horses on tramways is a misfit and a barbarism; and when the inertia of prejudice has become exhausted, the civiliser—mechanical power—will duly replace the horse as a motor."[15]

Despite the arguments of the mechanizers, evidence suggests that horses were quite well adapted to the demands of urban transportation. Proponents of mechanization generally avoided the question of capital costs, which were always less with animal power. Although coal was substantially cheaper than hay and oats, even in the most inefficient mechanical system, this advantage diminished substantially when maintenance and depreciation were included. Despite their short working life, retired streetcar horses could perform serviceably in other occupations, and returned a substantial percentage of their original purchase price. Compared to early mechanical systems, horses were quite reliable, being little injured by the dust and mud of nineteenth-century urban streets. Horse droppings also posed less of a problem than might be supposed, since the average streetcar horse only spent four hours daily outside of the stables, and much of the droppings could be returned as fertilizer to the farms that supplied the stables with hay.[16]

Limitations in the supply of unmechanized transit probably provided a more important spur to mechanization than the cost of horse feed.[17] The densely packed, rapidly expanding industrial cities of the post–Civil War era experienced unprecedented levels of street congestion. Streetcars, goods wagons, hackney coaches, and omnibuses vied for space in narrow streets. Under these conditions, horsecars averaged about 5 miles per hour. Even with very short headways between cars, a single set of tracks quickly reached maximum capacity. Despite the use of parallel streets, congestion remained high. In Philadelphia, for example, streetcar lines occupied almost every through street in the central district.[18] Finally, horsecar speeds remained limited to little more than a brisk walk, while urban areas continued to expand, creating a demand for faster forms of transit.

Given the success of the steam engine in intercity rail transportation, early proponents of mechanization quite naturally sought to apply steam to street railroads in a manner acceptable to urban residents. Cities had originally banned steam engines from their streets due to the smoke, noise, steam, and burning cinders emitted by early locomotives, and because steam engines often frightened horses. Inventors tried to eliminate the objections of urban residents by muffling the steam exhaust and by burning anthracite coal or coke to avoid smoke. Steamcar builders enclosed the working parts of the engine to make it resemble a horsedrawn streetcar. These disguised steamcars became known as "dummy" engines. Some steamcar builders combined a small steam engine and a passenger compartment in a single car, while others developed separate dummy engines to pull one or two passenger cars. By most accounts, the steam dummies emitted little visible smoke or steam, except in damp weather, and produced no more noise than a horsedrawn streetcar. Most observers of steam dummies in operation agreed that horses, although disturbed at first, quickly became used to the new vehicles. Some observers thought that steamcars would frighten horses less if they made more noise, since horses were apparently startled by the relative silence of the dummy's approach.[19]

Advocates of the dummy insisted that steam power cost less than horses. An 1877 article in *Engineering News* provides a typical comparison of horsecar and dummy, estimating weekly horse costs of $24, in contrast to a weekly coal consumption of 1.75 tons of anthracite at $8.75.[20] This comparison was somewhat disingenuous, since the cost for horse power almost certainly included "maintenance" in addition to feed, that is, the wages of hostlers, blacksmiths, and perhaps veterinarians, and also the costs of maintaining the stable itself. But even more careful cost estimates indicated a considerable advantage for steam. One British engineer who compared horse and steam streetcars, including estimates for depreciation and maintenance, calculated an operating cost of 8.67d. for horses, compared with 5d. for steam, still a substantial savings. He cautioned, however, that his estimate probably erred in favor of steam due to the uncertainty in maintenance costs.[21] Nevertheless, in terms of the total cost of motive power, steam streetcars appeared to have a definite cost advantage over horses.

American street railroads first adopted steam streetcars during the Civil War. Early experience with these steam streetcars seemed to confirm claims of lower costs, but street railroad companies did not turn to steam power on a large scale after the war. Steam street railroads received little attention from the technical press after the late 1870s, even though their numbers grew gradually, peaking at 815 cars and 642 miles of line in 1891.[22] At least one steam dummy line, from Frankford to Kensington in Philadelphia, operated quite successfully with steamcars from about 1861 to 1893.[23]

Several factors explain the reluctance of the street railroads to adopt steam despite its apparent cost advantage. Most cities continued to forbid steam dummies in central districts, despite the fairly successful efforts of inventors to make these cars inoffensive. Steam streetcars were thus consigned to outlying districts. A typical steamcar could haul twice as many passengers as a horsecar, but this advantage was largely wasted on lightly traveled suburban routes, though passengers did appreciate the greater speed of the dummy.[24] Serious maintenance problems also hindered the spread of the steam dummy. Conditions of street railroads differed considerably from those of mainline steam roads, making irrelevant a good deal of the experience of steam locomotive engineering. In particular, the streetcar running at street level faced much more dust and mud than a mainline locomotive running on a well-ballasted T-rail. Street dirt quickly destroyed exposed parts of the engine that would have lasted for years in mainline service.[25] Finally, lower prices for horse feed reduced the advantages of mechanization. The end of the Civil War ushered in an era of falling produce prices, particularly in farm products, which lasted until the 1890s.

Between the periods 1866–1870 and 1886–1890, for example, the price of corn fell 42 percent, oats 40 percent, and hay 37 percent. Although prices for coal also fell, declining materials prices reduced the advantage to be gained by replacing feed, a variable cost, with machinery, a fixed capital cost.[26]

While public opposition to mobile steam engines remained strong, city dwellers readily accepted stationary steam engines. One logical means for mechanizing urban transit, therefore, was to keep the steam engine fixed and transmit power to the streetcars by means of a moving cable. In 1873 San Francisco became the site of the first successful cable streetcar system, built by Andrew Hallidie (1836–1900), who had previously developed cable haulage machinery for mines. The Hallidie system provided a moving cable in a subsurface conduit located between the streetcar rails. The cars were attached to the cable by means of a releasable grip inserted in a narrow slot in the conduit. The cable system took hold in San Francisco because of its ability to mount steep grades, grades that made horsecar lines impractical. San Francisco remained the only city in the United States with cable traction until 1882, when Charles B. Holmes opened a large cable system in Chicago. Holmes, who was president of one of the largest street-railway systems in the country, believed that cable traction could be profitable on level terrain and in colder climates. Holmes proved correct, and cable systems spread to most major American cities by the early 1890s, reaching a peak of 305 miles in 1893. Route mileage, however, understates the relative importance of cable traction, since cable lines carried far more passengers per mile than horsecar lines. In 1890 cable systems carried annually 1.3 million passengers per mile of line, four times more than horsecar lines. In that year, cable systems accounted for 18 percent of all street-railway passengers.[27]

Despite the success of cable roads on heavily traveled routes in major cities, cable traction appeared unlikely to eliminate animal power. Cable systems required immense investments compared to horsecars, largely due to the heavy construction needed for the conduit and other machinery required to move the cable. This large fixed investment made cable traction practical only on routes with high traffic densities. Where such high traffic densities existed, power from the cable cost half as much as horse power per car mile.[28] Census data from a selection of cable roads in 1890 showed the costs of cable power to be 3.5¢/car-mile, including maintenance on the cable system and steam engines. The same report showed the costs of horse traction to be 6.1¢/car-mile, including the renewal of horses and all stabling costs. There were a number of attempts to modify cable technology to reduce construction costs, and thus make it practical for lighter traffic, but none of these succeeded before the rapid spread of the electric streetcar brought construction of new cable lines to a halt in 1895.[29]

While cable systems were spreading rapidly to large American cities, another form of motive power emerged as a serious competitor—electricity. In the United States, serious attempts to develop commercially viable electric traction began in the early 1880s, made possible by the improvements in the generation of electricity for lighting. Thomas Edison experimented with an electric locomotive in 1880, but devoted little effort to its commercialization. At the time, Edison hoped to compete with mainline steam railroads, rather than horsedrawn street railroads. Other inventors soon recognized the potential market offered by street railroads, and by the mid-1880s a number of systems were in commercial operation. These systems relied on direct-current (dc) dynamos driven by stationary steam engines, with the power transmitted to the vehicle by third rail, underground conduit, or overhead wire. Inventors used a variety of methods to connect the motor to the driving wheels, including belts, chains, friction drives, and various types of gears.[30]

These early electric streetcar systems received much favorable attention in the technical press, but they failed to thrive before 1888. At the beginning of 1888, there were only 13 electric railroads in the United States, with just over 48 miles of track and 95 cars, mostly operating on suburban routes or in small cities.[31] A good number of the earlier systems either returned to horse power or converted to cable.[32] In 1888, however, the tide turned in favor of electric traction. Historians generally credit the Richmond (Virginia) Union Passenger Railway, equipped by Frank J. Sprague (1857–1934), with providing the turning point in electric traction. Sprague's system, which opened in February 1888, was by far the largest built to that date, with 40 cars and 12 miles of track running through most of the city, including the downtown. Sprague assembled and perfected the basic arrangement of components that remained standard throughout the entire electric streetcar era, including the use of a single overhead wire and the flexible mounting of the motor underneath the car. Sprague's Richmond system directly inspired other street railroads to adopt electric traction, including the West End Street Railway of Boston, the largest street railroad in the United States.[33]

The impact of the Richmond system should not be overemphasized, however. In the summer of 1887, before Sprague had even begun work on the Richmond contract, 12 additional cities had begun building or had contracted to build electric streetcar systems, enough to double the number of electric street railroads in the United States.[34] Independently of Sprague, the Thomson-Houston company developed its own system of electric traction based on the work of Charles Van Depoele, whose company Thomson-Houston purchased. The first major Thomson-Houston system opened in July 1888, and subsequently the Thomson-Houston and Sprague companies roughly split the electric railway business until their merger in 1892.[35]

Beginning in 1888, electric streetcar systems began opening at a rapid and accelerating pace. With a few exceptions, electricity became the motive power of choice for new street railroads, and existing horsecar systems increasingly converted to electricity. By July 1, 1890, electricity powered almost 16 percent of American street railway track, and street-railway companies had spent almost 36 million dollars on electric railroads. Between 1888 and July 1890, 136 electric railroads began operating.[36] Just one year later, in July 1891, the number of electric railroads and miles of track had more than doubled.[37] By the end of 1893 fully 60 percent of American street-railway track had been electrified, reaching 98 percent by the end of 1903.[38] By the mid-1890s, electricity had become the dominant motive power on American street railroads.

The Role of Costs

Some historians have argued that cost advantages explain the triumph of electric traction over competing technologies. According to this view, sometime between 1887 and 1889 electricity clearly became cheaper than horse, steam, and cable power.

George Hilton specifies the beginning of electricity's superiority quite precisely: February 2, 1888, when Sprague opened his Richmond system. Before Sprague's success in Richmond, claims Hilton, cable traction had been "the most economic form of urban street transportation" from January 28, 1882, the opening of the first Chicago cable system.[39]

Perhaps Hilton has greater insight into the costs of competing street-railway systems than did the entrepreneurs of the time. But for street railway-men in the late nineteenth century, the costs of alternative systems hardly appeared so clear. Although proponents of specific systems always marshaled data showing that their methods had the lowest costs, other entrepreneurs and engineers emphasized the difficulty of obtaining comparable cost data and the uncertainty inherent in cost estimates. This uncertainty continued well into the 1890s. For example, an 1897 editorial in the *Street Railway Journal,* titled "The Battle of the Motive Powers," admitted that "the difficulties of making true [cost] comparisons are almost insuperable."[40] When an 1890 comparison of steam and electric locomotives on the Manhattan Elevated suggested that electricity would cost four times more than steam, a stormy debate ensued in the technical press over how to interpret the results.[41] A similar debate occurred in 1894 when the eminent railroad engineer Hermann Haupt (1817–1907) criticized the proposed use of electricity for rapid-transit lines.[42] The annual conventions of the American Street Railway Association produced lively discussions on the costs of various systems, discussions that revealed the ambiguities of cost comparisons. During the 1889 convention, for example, the operator of a Sprague trolley system in East Cleveland declined to give any quantitative estimate of his cost savings over horses, insisting that five to six years of experience were needed before one could calculate the savings accurately.[43] If comparative costs had been as clear as Hilton claims, serious professionals would not have wasted their time debating such questions.

Comparing the costs of emerging technologies is always difficult, but several factors made such comparisons especially problematic on street railroads. In the first place, street railroads did not use uniform methods of cost accounting.[44] The cost of motive power, for example, did not always include real estate, depreciation, or interest: With horses, depreciation and maintenance could be accurately measured using historical data, but depreciation for mechanical systems remained speculative, especially during the first few years of operation. Even when two street railroads used the same motive power, costs varied considerably due to differences in operating conditions, most notably the number and steepness of grades. Costs were commonly given in cents per car-mile, which neglected differences in thecapacity of cars, or cents per passenger, which ignored differences in length of travel. Street railroads did not use the modern measure of costs per passenger-mile until after 1900.[45] Finally, street railroads had monopolies along their specific routes, so there was no threat of direct competition to correct systematic biases in cost accounting.

Street-railroad companies had particular problems handling capital costs because of the widespread practice of stock watering. A common fraud followed the pattern of the Credit Mobilier scheme, in which a street railroad paid inflated prices to construction firms in which the principals of the street railroad had an interest.

Even where there was no outright fraud, street railroads commonly used company stock to pay for construction, stock that the construction company accepted at a steep discount, but which the street railroad listed at par, thus substantially overstating construction costs.[46] In 1890 Census data, horse railroads with similar traffic densities reported total costs for road and equipment ranging from $30,000 to $144,000 per mile of track, clear evidence of questionable capital accounting.[47]

The difficulties posed in obtaining accurate cost comparisons should raise doubts about Hilton's certitude. Even if Hilton did have an objective method for measuring costs retrospectively, we would still need an explanation for why street-railway companies chose electricity, since the companies clearly lacked access to such information. The triumph of electric traction undoubtedly brought a great increase in the supply of urban transit and a significant reduction in cost, especially if measured in cost per passenger-mile. John P. McKay convincingly demonstrates these cost savings in his analysis of data for Britain and France between 1896 and 1910.[48] Nevertheless, evidence for lower costs after the conversion to electricity does not explain why street-railway companies chose electricity in the first place, especially in the period from late 1887 through 1890.

A good example of the ambiguity of cost data is provided by Frank Sprague's Richmond trolley system, now considered the turning point in the success of electric traction. One would have expected Sprague to use his Richmond installation to generate detailed cost information to convince doubters of its economy. In June 1888 Sprague did present some data on the cost of motive power in Richmond, but these figures were only estimates, although based on actual data. Sprague calculated the cost of motive power at 4.32¢/car-mile, which he said was 40 percent less than the cost to operate the same number of horse cars under similar conditions. Sprague included reasonable estimates for depreciation, though his estimates for repairs appear somewhat low.[49]

Sprague did not continue to present cost data on the Richmond system, however. He turned the operation of the Richmond road over to its owners after their formal acceptance of the system on May 15, 1888.[50] As soon as Sprague withdrew from direct supervision of the system, it began to fall apart. When Sprague appeared at the annual American Street Railway Association (ASRA) convention in October 1888, he provided no detailed cost data. Several delegates questioned him about maintenance problems they had observed on recent visits to Richmond. One delegate found only 12 of the normal 30 cars in operation, due, he was told, to burned out motors. Another delegate discovered 18 men employed in the repair shops to care for 40 cars. In response, Sprague claimed that the road's owners had engaged in "the grossest mismanagement," neglecting maintenance and overloading the motors. Within a year, the Richmond system was in the hands of receivers, and barely operating. The receivers found themselves unable to determine operating costs.[51]

The problems with the Richmond system did not appear to hurt the Sprague company's business. By October 1888, the company had 28 contracts to install trolley systems, including one line on Boston's West End Railway.[52] The management of the Richmond system had undoubtedly been incompetent and corrupt. Nevertheless, the owners had probably not intended to reduce their company to insolvency in little more than a year; the electric system apparently proved less profitable than they had expected.

Sources of Success: Enthusiasm and Structure

Costs clearly seem inadequate to explain the turn to electric traction after 1877. Installations made before 1888 were either failures or marginal, and even Sprague's Richmond system did not operate reliably. In the late 1880s, street railways made large-scale commitments to electricity, providing a crucial impetus to the electric traction industry, raising its scale, advancing it down the learning curve, and focusing inventive effort on the perfection of electric traction. This early commitment was central to the trolley's overwhelming success against competing technologies in the 1890s.

Although explanations for the trolley's early success must remain somewhat speculative, two factors appear central. First is the nearly universal enthusiasm for electrical technology, an enthusiasm that did not extend to cable or steam streetcars. This enthusiasm for electricity encouraged an optimistic interpretation of its costs, and helped convince street-railway companies to invest in electric systems. The second key factor was the place of electric traction in the electric lighting industry. The trolley provided an additional market for manufacturers of central station equipment, and it also promised to make the electric lighting business more profitable by providing a daytime load for central generating stations. Because of this relationship, central-station interests provided essential support to the development of electric traction.

David Nye has ably documented American enthusiasm for electrical technology in the late nineteenth century. Popular enthusiasm for electricity far outstripped fear of this invisible and potentially lethal power. Various forms of conspicuous consumption provided an important early market for electric lighting.[53] Some businessmen in the electric lighting industry recognized the importance of this enthusiasm for their business. "The novelty of the electric light has largely been its stock in trade," wrote Alexander Stuart, an executive in an Edison subsidiary, to Alexander Insull in 1884. Stuart noted that recently improved gas burners were as bright as the standard Edison lamp. Stuart warned Insull that the novelty of the electric light would soon fade, and Americans would then "pant for something else."[54] Improved electric lighting systems eventually met the challenge of gas. Popular enthusiasm played a crucial role in this success, propelling the electric light down the learning and innovation curve during the early period when its profitability remained questionable. A similar enthusiasm played a rôle in the development of the electric streetcar.

Street-railway owners and managers fully shared the public's enthusiasm for electrical technology. One would think that these businessmen, comfortable with the world of horses, iron rails, and cobblestone paving, would have approached electricity with considerable skepticism, demanding proof of its economy and reliability before risking an investment in the new technology. Such skepticism existed to some extent, especially before 1888, but skepticism was overshadowed by palpable excitement over the potential of electric traction, and a widespread belief in the certainty of its application to street railroads.

ASRA's annual conventions provide striking evidence of enthusiasm for electric traction among street-railway men. In a brief address at the 1883 convention, association president H. H. Littell labeled electric traction as "the last and greatest discovery of the century." According to Littell, the "crude experiments already made with electricity as a motive power . . . clearly foreshadow the inevitable application of the new motor to our immediate interests."[55]

Passionate rhetoric in support of electricity continued in subsequent conventions, often phrased in the language of evangelical religion.[56] No member of the association surpassed in eloquence Calvin A. Richards, manager of the Metropolitan Railroad of Boston. At the 1884 convention, Richards likened electric traction to an infant, conferred by the Creator "as a new blessing on the world." Richards protested his ignorance of matters electric, but such ignorance did nothing to blunt his enthusiasm. In fact, technical details mattered little to Richards. "I care not what one tells me of the crude developments of [electric traction] today," argued Richards. For Richards, the dramatic technical progress that he had personally witnessed, especially the telegraph and telephone, convinced him that electricity's success was certain: "The next step, . . . as sure as God reigns, is going to be electricity!" Although Richards was not urging his colleagues to convert immediately to electricity, his belief in its inevitability convinced him to forgo other forms of mechanization while awaiting the perfection of the electric streetcar.[57]

Delegates rarely challenged this enthusiastic rhetoric. At the 1886 convention, however, one delegate did take exception to the dominant rhetoric. This delegate recalled Richards's metaphor of electricity as infant in order to dispute it. "I think that electricity is a pretty tough old maiden by this time," he said, and called for a "thorough discussion" of the reasons why electricity "has not reached that giant strength that Mr. Richards has foretold."[58] These incompatible metaphors for electricity were not empty rhetoric, but had direct implications for the technical choices being made by street-railway companies. If electricity was a "pretty tough old maiden" rather than an infant, then there was no reason to postpone cable or steam systems in anticipation of electric traction.

Enthusiasm for electric traction played an important role in the interpretation of cost data. Given the uncertainty of cost estimates, it would have been reasonable to greet claims for the economy of electric traction with considerable skepticism. But electrical enthusiasm ensured that street-railway men would give such cost data an optimistic interpretation. No one demanded an accurate accounting of capital costs. Unrealistic estimates of depreciation and maintenance passed without comment. Probing questions were often treated as insults, unworthy of response.[59]

By the early 1890s, this optimism had proved justified, at least as far as competition with horses was concerned. Electricity appeared to be the most economical power for a wide range of traffic densities, though horses still seemed preferable on lightly traveled lines, and cable traction appeared superior for very heavy traffic.[60] The belief of street-railway men in the success of electric traction was partly self-fulfilling, due to their willingness to invest in electric traction before obtaining accurate cost data. Before 1888, however, street railroads invested little money in electric traction. These companies would have found no electric traction systems to buy if the manufacturers of electric lighting equipment had not supported the development of electric streetcars.

Frank Sprague's relationship with the Edison companies illustrates the key role of central station interests in the development of electric traction. Without an electric motor load, most electric lighting plants had very poor load factors, since there was often insufficient power to operate them during the day. Edison recognized as early as 1878 that the addition of a motor load would improve the load factor of central plants, and thus improve the profitability of the investment.[61] Before the adoption of electric traction in the late 1880s, however, there was little opportunity for central stations to share motor and lighting loads.

Throughout his work on electric traction, Sprague remained intimately involved with the companies controlled by Thomas Edison and his associates. This close involvement continued despite personal animosity between Sprague and Samuel Insull, the manager of Edison's business interests. Sprague had worked briefly for Edison from 1883 to 1884, when Sprague left to seek fame and fortune as an independent inventor, modeling himself explicitly on Edison. Sprague soon patented an improved electric motor, and he formed the Sprague Electric Railway and Motor Company to develop and market it. Sprague's chief source of capital was Edward H. Johnson, a close associate of Edison and later president of the Edison Illuminating Company. The Sprague company contracted with the Edison Machine Works to manufacture the motors, and the Edison interests urged their central stations to promote sales of the Sprague motor in order to obtain a daytime load. The Sprague motor constituted a sizable part of the business at the Edison Machine Works.[62]

While Sprague was making a handsome profit selling electric motors, he diverted as much cash as possible to his electric traction experiments. Despite frequent complaints from Insull, Sprague repeatedly paid his bills late and disputed charges. Insull tolerated Sprague's behavior because of the importance of Sprague's work to the Edison system. The Edison Machine Works in effect provided Sprague with considerable additional capital by permitting him to pay his bills late. When Sprague needed more funds to promote his business, Edison's associates purchased the stock. After the success of Sprague's system became assured by 1889, the newly formed Edison General Electric purchased Sprague's company and forced him out of its management.[63]

The Thomson-Houston Company, Edison's chief competitor, also actively entered the electric traction business in early 1888 by purchasing Charles Van Depoele's company. Van Depoele was undoubtedly the leading supplier of electric traction systems before Sprague's success in Richmond. After buying the Van Depoele system, Thomson-Houston supplied the necessary capital and manufacturing expertise to make the system suitable for application on a large scale. Once again, the manufacturers of electric lighting equipment proved crucial to the success of electric traction.[64] Neither the horses, steam dummies, nor cable cars found similar dynamic and powerful allies in the American industrial structure.

Conclusion

No prudent historian would seriously argue that technical choice can be reduced to a matter of costs. Nevertheless, it is surprising how unimportant actual cost data were in the early success of electric traction. American street-railway companies invested $36,000,000 in electric railroads by mid-1890, mainly on the basis of speculative cost estimates.[65] For most of these street railroads, faith in electricity proved justified. Costs declined rapidly in the 1890s as manufacturers progressed rapidly down the learning curve. The price of electric motors for a single streetcar fell from $4500 in 1889 to $750 in 1895.[66] With the spread of rotary converters, street railroads were able to share the lower costs of alternating current (ac) generated by steam turbines and water power.[67] The electric streetcar spread far and wide, providing urban residents with cheap and plentiful transportation, while opening up huge areas to residential settlement. However, the subsequent costs of electric traction cannot serve as an explanation for the initial choice of electricity, since the early investors did not have access to the future.

Notes

1. See George Rogers Taylor, *The Transportation Revolution, 1815–1860* (New York: Rinehart, 1951).
2. John P. McKay, *Tramways and Trolleys: The Rise of Urban Mass Transport in Europe* (Princeton, N.J.: Princeton Univ. Press, 1976), pp. 50–51, 68–73; Clay McShane, *Technology and Reform: Street Railways and the Growth of Milwaukee, 1887–1900* (Madison: State Historical Society of Wisconsin for the Department of History, University of Wisconsin, 1974), pp. 1–10; George Rogers Taylor, "The beginnings of mass transportation in urban America," *Smithsonian J. Hist.*, Vol. 1, Summer 1966, pp. 35–40; Autumn 1966, pp. 39–52.
3. For different explanations of this competition in Europe, see McKay, *Tramways and Trolleys*, op. cit., pp. 25–67, and Anthony Sutcliffe, "Street transport in the second half of the nineteenth century: Mechanization delayed?" in *Technology and the Rise of the Networked City in Europe and America*, eds. Joel A. Tarr and Gabriel Dupuy (Philadelphia: Temple Univ. Press, 1988), pp. 22–39.
4. On the neoclassical (i.e., naive) theory, see Jon Elster, *Explaining Technical Change* (Cambridge, England: Cambridge Univ. Press, 1983), pp. 96–111; for a trenchant critique of this approach, see Paul A. David, *Technical Choice, Innovation and Economic Growth* (Cambridge, England: Cambridge Univ. Press, 1975), pp. 4–16.
5. Paul A. David, "Clio and the economics of QWERTY," *Am. Econ. Rev.*, Vol. 75, May 1985, pp. 332–336.
6. Thomas P. Hughes, "The development phase of technological change," *Technol. Culture*, Vol. 17, 1976, pp. 429–430.
7. The classic example is the diesel engine. See Lynwood Bryant, "The development of the diesel engine," *Technol. Culture*, Vol. 17, 1976, pp. 432–446.
8. Nathan Rosenberg, "Learning by using," in *Inside the Black Box: Technology and Economics* (Cambridge, England: Cambridge Univ. Press, 1982), pp. 120–140.

9. David, "Clio and the economics of QWERTY," op. cit., pp. 332–336; Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, Mass.: M.I.T. Press, 1990), p. 168.

10. The best brief summary of the mechanization of American street railroads is McShane, *Technology and Reform*, pp. 6–17. On conversion of early electric systems to cable, see George W. Hilton, *The Cable Car in America: A New Treatise upon Cable or Rope Traction as Applied to the Working of Street and Other Railways*, rev. ed. (San Diego: Howell-North, 1982), p. 17. On 1888 as the turning point for electricity, see Eugene Griffin, "Three years' development of electric railways," *National Electric Light Association, Proceedings*, Vol. 14, September 7, 1891, pp. 234–235.

11. McKay, *Tramways and Trolleys*, op. cit., pp. 13–15; Taylor, "The Beginnings of Mass Transportation in Urban America," Autumn 1966, op. cit. pp. 33–39.

12. McKay, *Tramways and Trolleys*, op. cit., p. 14; Daniel Kinnear Clark, *Tramways, Their Construction and Working*, 1st ed. (London: Lockwood, 1878), p. 6; "American street railroads," *All Year Round*, Vol. 5, April 6, 1861, pp. 40–44.

13. *Report on Transportation Business in the United States at the Eleventh Census, 1890*, Vol. 1 (Washington, D.C.: U.S. Government Printing Office, 1894), p. 681.

14. McKay, *Tramways and Trolleys*, op. cit., p. 26; Clark, *Tramways*, op. cit., p. 416.

15. Clark, ibid.

16. F. M. L. Thompson, "Horses and hay in Britain, 1830–1918," in *Horses in European Economic History: A Preliminary Canter*, ed. F. M. L. Thompson (Reading, England: British Agricultural History Society, 1983), p. 64; F. M. L. Thompson, "Nineteenth-century horse sense," *Econ. Hist. Rev.*, Vol. 29, 2nd ser., 1976, pp. 60–81.

17. See McKay, *Tramways and Trolleys*, op. cit., p. 52.

18. *Philadelphia City Passenger Railway Guide and Advertising Medium, Embracing the Routes of City Passenger Railways* (Philadelphia: F. I. Mitchell, 1874).

19. Massachusetts Street Railway Commission, *Evidence Before the Street Railway Commissioners Appointed by the Massachusetts Legislature, Session of 1863–4* (Boston: Wright & Potter, Printers, 1864), pp. 89–95, 99, 102–110, 116–126; Baldwin Locomotive Works, Philadelphia, *Noiseless Motors and Steam Street Cars for City and Suburban Railways*, 3rd ed. (Philadelphia: Lippincott, 1890), Historical Society of Pennsylvania Library; "Trial of a steam street car," *The Railroad Gazette*, Vol. 8, April 28, 1876, p. 183; Clark, *Tramways*, op. cit., pp. 312–414.

20. "Steam on street railways," *Eng. News*, Vol. 4, March 10, 1877, p. 59. See also "Steam on street railways," *J. Franklin Inst.*, Vol. 103, 1877, p. 384; "Steam traction for tramways," *Street Railway Gazette*, Vol. 1, September 1886, pp. 264–265.

21. Robinson Souttar, "Street tramways," *Minutes of the Proceedings of the Institution of Civil Engineers*, Vol. 50, Part 4, April 24, 1877, pp. 18–19; for a similar British estimate, see Clark, *Tramways*, op. cit., p. 416; Richard Clere Parsons, "The working of tramways by steam," *Minutes of the Proceedings of the Institution of Civil Engineers*, Vol. 79, 1885, pp. 113–119.

22. "Comparison of mileage and cars of street railways in the United States for the years 1890–91," *Street Railway J.*, Vol. 8, April 1892, p. 213.

23. John H. White, "Grice and Long: Steam-car builders," *Prospects: An Annual of American Cultural Studies*, Vol. 2, 1976, p. 30.

24. Derek H. Aldcroft, "Urban transport problems in historical perspective," in *Business, Banking and Urban History: Essays in Honour of S. G. Checkland*, eds. Anthony Slaven

and Derek H. Aldcroft (Edinburgh: John Donald, 1982), p. 224; Massachusetts Street Railway Commission, *Evidence*, op. cit., pp. 106, 110, 124; McShane, *Technology and Reform*, op. cit., p. 8.

25. *ASRA Proceedings*, Vol. 2, 1883, pp. 89–90; *ASRA Proceedings*, Vol. 6, 1887, pp. 68–69; McKay, *Tramways and Trolleys*, op. cit., p. 30; John H. White, "Steam in the streets: The Grice and Long dummy," *Technol. Culture*, Vol. 27, 1986, pp. 108–109; Clark, *Tramways*, op. cit., p. 419.
26. *Historical Statistics of the United States: Colonial Times to 1957* (Washington D.C.: U.S. Bureau of the Census, 1960), pp. 297–298, 302; Sutcliffe, "Street transport in the second half of the nineteenth century," op. cit., p. 29.
27. Hilton, *The Cable Car in America*, op. cit., pp. 13–14, 17–27, 44; *Report on Transportation Business in the United States at the Eleventh Census*, 1890, op. cit., p. 682.
28. "Report of the committee on the cable system of motive power," *ASRA Proceedings*, Vol. 3, 1884, p. 147.
29. Hilton, *The Cable Car in America*, op. cit., pp. 40, 103; Charles H. Cooley, *The Relative Economy of Cable, Electric, and Animal Motive Power for Street Railways*, Census Bulletin No. 55 (Washington, D.C.: U.S. Department of the Interior, Census Office, 1891).
30. The best scholarly account of early electric traction developments in the United States remains Harold C. Passer, *The Electrical Manufacturers, 1875–1900: A Study in Competition, Entrepreneurship, Technical Change, and Economic Growth* (Cambridge, Mass.: Harvard Univ. Press, 1953), pp. 211–236. For a more detailed but less scholarly discussion, see John R. Stevens, ed., *Pioneers of Electric Railroading: Their Story in Words and Pictures* (New York: Electric Railroaders' Association, 1991).
31. Griffin, "Three years' development of electric railways," op. cit., p. 235. Griffin's figures are substantially less than those given in William D. Middleton, *The Time of the Trolley: The Street Railway from Horsecar to Light Rail*, Vol. 1 (San Marino, Calif.: Golden West, 1987), p. 65.
32. Hilton, *Cable Car in America*, op. cit., p. 17.
33. Passer, *Electrical Manufacturers*, op. cit., pp. 242–248.
34. T. Commerford Martin, "A few comparative statistics of electric railways," *AIEE Transactions*, Vol. 4, 1887, pp. 183–187.
35. Passer, *Electrical Manufacturers*, op. cit., pp. 248–253. The Sprague Electric Railway and Motor Company was bought by Edison General Electric at the end of 1889. In 1892 Edison General Electric merged with Thomson-Houston to form General Electric.
36. *Report on Transportation Business in the United States at the Eleventh Census*, 1890, op. cit., pp. 681–682.
37. Griffin, "Three years' development of electric railways," op. cit., p. 235.
38. McKay, *Tramways and Trolleys*, op. cit., pp. 50–51.
39. Passer, *Electrical Manufacturers*, op. cit., pp. 253–254; Hilton, *The Cable Car in America*, op. cit., p. 149.
40. "The Battle of the Motive Powers," *Street Railway J.*, Vol. 13, October 1897, pp. 650–653.
41. Lincoln Moss, "Comparative tests of an electric motor and a steam locomotive on the Manhattan (Elevated) Railway," *The Railroad Gazette*, Vol. 22, July 11, 1890, pp. 488–489; "Efficiency of the locomotive and electric motor," *The Railroad Gazette*, Vol. 22, July 11, 1890, pp. 494–495; Lincoln Moss, "Efficiency of the locomotive and electric motor," *The Railroad Gazette*, Vol. 22, July 18, 1890, pp. 503–504. See also the discus-

sion following Moss, "Comparative Tests of an Electric Motor and Steam Locomotive on Manhattan (Elevated) Railway, New York," *ASCE Transactions*, Vol. 23, October 1890, pp. 193–216.

42. Some of these articles are collected in Hermann Haupt, *Rapid Transit in New York; Open Letter to A. S. Hewitt, on the Various Motive Power Systems Proposed for the Operation of Rapid Transit Lines in the City of New York* (Washington D.C.: Adams, 1894). See also Haupt, *Street Railway Motors: With Descriptions and Cost of Plants and Operation of the Various Systems in Use or Proposed for Motive Power on Street Railways* (Philadelphia: Henry Carey Baird, 1893). Both these sources are detailed arguments in support of compressed-air motors.
43. "Remarks of Dr. A. Everett," *ASRA Proceedings*, Vol. 8, 1890, p. 74.
44. "Report of the Committee on 'A Uniform System of Accounts'," *ASRA Proceedings*, Vol. 3, 1894, p. 153.
45. McShane, *Technology and Reform*, op. cit., pp. 34–35.
46. Massachusetts Street Railway Commission, *Report . . . to the General Court*, Massachusetts House Rep. No. 15 (Boston: Wright & Potter, 1865), pp. 30–34; Robert B. Carson, *What Ever Happened to the Trolley* (Washington, D.C.: Univ. Press of America, 1978), pp. 29–32, 51–52; McShane, *Tramways and Trolleys*, op. cit., p. 34.
47. Cooley, *The Relative Economy of Cable, Electric, and Animal Motive Power*, op. cit., pp. 5–6. Calculations based on horse railroads numbered 1 through 6, table I.C.1.
48. McKay, *Tramways and Trolleys*, op. cit., pp. 58–61.
49. Frank J. Sprague, "The solution of municipal rapid transit," *AIEE Transactions*, Vol. 5, August 1888, p. 387.
50. Richmond Union Passenger Railway Company to Edward H. Johnson, Sprague Electric Railway and Motor Company, May 15, 1888, Frank J. Sprague papers, New York Public Library, box 1, folder 1887–88.
51. "Remarks of Mr. F. J. Sprague on Electric Railways and Motors," *ASRA Proceedings*, Vol. 7, 1888, pp. 101–109; "Remarks of Mr. John S. Wise on the Richmond Electric Road," *ASRA Proceedings*, Vol. 8, 1889, pp. 68–73.
52. *ASRA Proceedings*, Vol. 7, op. cit., p. 103.
53. David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880–1940* (Cambridge, Mass.: M.I.T. Press, 1990), pp. 85–137.
54. A. Stuart to Alexander Insull, April 17, 1884, *Thomas A. Edison Papers: A Selective Microfilm Edition*, Part II (Frederick, Md.: Univ. Publications of America, 1987), Vol. 75, p. 125.
55. "Address of the President," *ASRA Proceedings*, Vol. 2, 1883, pp. 8–9.
56. For an example of this rhetoric in aviation, see Joseph J. Corn, *The Winged Gospel: America's Romance with Aviation, 1900–1950* (New York: Oxford Univ. Press, 1983).
57. Remarks of C. A. Richards, *ASRA Proceedings*, Vol. 3, 1884, pp. 138–140.
58. Remarks of C. B. Holmes, *ASRA Proceedings*, Vol. 5, 1886, p. 86.
59. See, for example, remarks of Mr. Wharton, *ASRA Proceedings*, Vol. 5, 1886, p. 88; remarks of C. A. Richards, ibid., p. 94; remarks of Mr. Wharton, *ASRA Proceedings*, Vol. 6, 1887, p. 44.
60. R. J. McCarty, "Special report concerning the relative cost of motive power for street-railways," *ASRA Proceedings*, Vol. 9, 1890, pp. 70–74.
61. Passer, *Electrical Manufacturers*, op. cit., p. 218.

62. Frank J. Sprague to Thomas Edison, April 24, 1884, *Edison Papers*, op. cit., Vol. 74, p. 754; C. H. Coster, "Report of the special committee on the use of sprague motors," May 25, 1885, *Edison Papers*, op. cit., Vol. 77, p. 747; F. S. Hastings to the owners of Central and Village Station Companies, May 25, 1885, *Edison Papers*, Vol. 74, p. 749; Contract between the Edison Electric Light Company and the Sprague Electric Railway and Motor Company, June 16, 1885, *Edison Papers*, Vol. 88, p. 954. See also Harold C. Passer, "Frank Julian Sprague: Father of electric traction, 1857–1934," in *Men in Business: Essays in the History of Entrepreneurship*, ed. William Miller (Cambridge, Mass.: Harvard College, 1952), pp. 212–237.
63. Samuel Insull to Edward H. Johnson, April 7, 1887, D8736ABC; Insull to A. O. Tate, February 21, 1887, D8736AAQ; Frank J. Sprague to Johnson, April 11, 1887, D8736ABI; Insull to Edison, November 5, 1887, D8736AEL; J. H. McClement, "Supplementary report on financial condition, earnings and business of the Sprague Electric Railway and Motor Company," January 31, 1889, D8944AAB, Thomas A. Edison Papers, Edison National Historical Site, West Orange, N.J.; [Frank J. Sprague] to W. W. Gooch, November 21; Sprague to President and Board of Directors, Edison General Electric Co., December 2, 1890, Frank J. Sprague papers, New York Public Library, box 1.
64. Passer, *Electric Manufacturers*, op. cit., pp. 233, 249–250.
65. *Report on Transportation Business in the United States at the Eleventh Census, 1890*, op. cit., p. 682.
66. Passer, *Electrical Manufacturers*, op. cit., p. 264.
67. Sydney W. Ashe, *Electric Railways Theoretically and Practically Considered*, Vol. 2, *Engineering Preliminaries and Direct-Current Sub-Stations* (New York: Van Nostrand, 1907); Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, Md.: Johns Hopkins Univ. Press, 1983), pp. 120–126, 208–212.