The Steam Engine in the United States

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Beginning with the first high-pressure steam engine used for transportation, adapted from Watt’s original steam engine by Oliver Evans in the United States, and Trevithick’s first steam locomotive in Britain, steam-powered railroads grew to become the dominant form of overland transportation for the United States in the 19th Century before being replaced by electric and diesel-electric trains in the early 20th Century. The American railroad began as a network connecting the densely populated eastern states before expanding westward with the first transcontinental railroad. The primary impetus for the western railroads was the government’s desire to gain greater control over western lands both politically and militarily. As a result, the government issued land grants and loans to railway companies in return for building the western railroads which were originally not able to be profitable on their own. As the railways became more widely used and commercially profitable, a number of technological advancements were made to improve the performance, efficiency, and safety of steam trains. Examples of these improvements include the compound locomotive—which derived mechanical power from the steam in two stages—and centrally-controlled air brakes—which allowed the engineer to simultaneously control the brakes on all the cars from the engine. The steam locomotive, however, was eventually replaced by all-electric and diesel-electric engines, which, despite the numerous improvements in steam locomotion, achieved higher performance and reduced maintenance costs.

The earliest vehicle with an engine closely resembling that of the steam locomotive was built by the American inventor Oliver Evans. After conducting “experiments on high-pressure steam in Philadelphia in 1784,”[[1]](#footnote-1) Evans obtained a patent for his engine which “particularly describes the application of his engine to wheel carriages.”[[2]](#footnote-2) Evans made the pioneering innovation of using his high-pressure steam engine for transportation. Because there were no railroads in America at the time, in 1804 Evans’ engine was first used to power a motorized carriage. On its maiden voyage the “*Oructer Amphibolos* . . . traversed the streets of the city until it arrived at the Schulykill, a distance of one mile and a half.”[[3]](#footnote-3) Although, Oliver Evans did not earn the distinction of inventing the steam locomotive, his engine would later be applied to that purpose.

The first use of a high-pressure steam engine on rails was accomplished by the British inventor Richard Trevithick. Trevithick built upon Evans’ work such that his engine was “constructed upon identically the same principle as the high-pressure steam engine, which was brought into being through the efforts of Oliver Evans.”[[4]](#footnote-4) The first steam locomotive, utilized Evans’ development of the high-pressure steam engine and merely applied the engine to railway rather than road transportation. This step “gives Trevithick the credit of the introduction of the steam engine on *railways* in 1804”[[5]](#footnote-5) The development of locomotives like Trevithick’s would go on to inspire the vast American railroad network.

The American railroads began as commercial enterprises in the densely populated north-eastern states. One of the first major railroads was built by a coalition of “merchants and traders in Baltimore and Philadelphia” who sought to “capture a share of the agricultural bounty that was flowing east via the Erie Canal to New York City.”[[6]](#footnote-6) The first railroads in the US served intraregional economic purposes, acting as competition to shipping by rivers and canals. As the north-east industrialized, “a network of railroads from the Atlantic Ocean to the Mississippi River had created an industrial heartland that extended to Chicago.”[[7]](#footnote-7) This network sprung up mostly as a result of private economic initiative as investors and builders sought to take advantage of the growing shipping and trade that resulted from the American industrial revolution.

Whereas the eastern railroads developed primarily as a result of private entrepreneurship, the western railroads were built primarily as a government initiative. One of the key proponents of the first transcontinental railroads was the U.S. military which saw that the “all-weather, rapid-transport capabilities of railroads were ideally suited to repelling invasions, pacifying Native Americans, suppressing slaves, and moving troops, supplies, and commercial goods in wartime.”[[8]](#footnote-8) The railroad was seen as a key instrument for expanding the United States’ control of the continent westward. The railroad would bring the western regions into close communication with the east, which would lead to more unification through trade as well as centralized political control.

Because the transcontinental railroads were mainly of interest to the government rather than private firms, it was necessary for the government to offer land grants to developers. The transcontinental railroads were not built with an expectation of “immediately earning a sufficient amount to make the enormous investment in their construction profitable.”[[9]](#footnote-9) Little traffic—both in terms of passengers and freight—could be expected on the western railroads at first and their enormous lengths necessitated a mammoth investment of capital upfront to build a continuous line from the Mississippi to the Pacific. As a result, the “government had to hold out inducements to [railroad developers] to invest their money by giving them land grants and making them loans.”[[10]](#footnote-10) In order to overcome the lack of profit expected from the transcontinental railroads, the United States government paid for their construction in the form of one of its most plentiful commodities at the time—land.

The land grant incentive was very effective and the American railroad system effectively expanded westward. In less than half a century after the completion of the first transcontinental railroad, the United States had eight major western railroad lines which began east of the Mississippi River as far north as Duluth, Minnesota and as far south as New Orleans, Louisiana, before ending on the Pacific coast in cities ranging from Seattle in the north and San Diego to the south.[[11]](#footnote-11) What began as a single line, heavily incentivized by the government, grew into a network of interconnected main lines and subsidiary tracks. By 1911, over 47,000 miles of track had been laid west of the Mississippi river with a total investment of over two billion dollars.[[12]](#footnote-12) While land grants and government support were needed to build the first transcontinental railroads, they quickly became independently profitable as the goals of developing the west and bringing it into closer communication with the east were accomplished.

The western railroads in the United States quickly joined their eastern counterparts as a profit-producing industry. The railroads linked different regions and cities together, stimulating their economies and in-turn creating more business for the railroads. They created a “direct contribution to income through the provision of transport services”[[13]](#footnote-13) and provided an “indirect contribution to development through stimulation of industries such as iron and steel, coal, and lumber.”[[14]](#footnote-14) This inter-regional, inter-industry stimulation quickly turned the railroads into a profit producing industry. In 1911, the western railroads brought in over $500 million of revenue, which made the “competition between these seven roads, both for freight and passenger business . . . very keen.”[[15]](#footnote-15) The growth of the railroad industry and the competition between different companies led to new investments to improve the technology.

Numerous improvements were made to Oliver Evans’ original high-pressure steam engine to improve performance. These included the compound locomotive, larger fireboxes, mechanical stoking, and superheated steam. The first of these innovations was the compound locomotive, invented by Jules-Theodore-Anatole Mallet, which learned from the construction of stationary steam engines and “made the steam work twice” once through “a high-pressure cylinder, from which it passed after partial expansion into a larger low-pressure cylinder.”[[16]](#footnote-16) The compound locomotive allowed more performance to be squeezed out of a given amount of steam, but it also increased the size of engines. Further adding to locomotives’ size were changes to the firebox that began to be introduced in the 1890s. These fireboxes were “wider, longer, and more efficient,” but they “necessitated the introduction of trailing wheels of small diameter which could be placed under the firebox so that it could be built over the wheels to the full width of the locomotive rather than confined to the space between the wheels.”[[17]](#footnote-17) The steam engines were forced to continue to get bigger in order to improve efficiency and performance.

The increased size of locomotives was not without a cost. These larger engines were increasingly difficult to operate on railroad tracks built for smaller engines. In his personal account of his experiences as a railroad engineer, William Gould recalls stating that he originally did not want to go work for the Utah lines because he did not “want to run a big old mallet.”[[18]](#footnote-18) His experiences showed how the tracks were not built to handle the longer and heavier engines that resulted from the pursuit of increased performance. He recalls on one occasion while attempting to flip an engine around, after “that monstrous piece of machinery put its full weight on that turntable the poor table gave a despairing sigh and settled down several inches.”[[19]](#footnote-19) Not only the weight, but also the length of these engines created problems. Regarding the Utah Railway’s lines, Gould states “[n]one of those curves on those wyes seemed ready to perform under the weight of those huge 2-10-2s”[[20]](#footnote-20)—that is an engine with two leading wheels, ten driving wheels, and two trailing wheels which were most likely under an oversized firebox as discussed above. The longer locomotives necessitated by Mallet’s compound engine and larger fireboxes had considerable difficulty making the sharp turns on the tracks that were designed for shorter engines.

These difficulties were in-part due to the hasty construction of the original transcontinental railroads and partly due to the slowness of advancements in locomotive wheel designs. Because the original western railroads were built to receive land grants by satisfying the government’s goal of building transcontinental lines rather than to be commercially profitable, they were not built to be of the best quality. Mileage was more important than the usefulness of the railroads themselves “many of which sacrificed performance in order to keep expenses low.”[[21]](#footnote-21) The oldest transcontinental lines were built as cheaply as possible.

Wheel configurations?

Mechanical stoking and superheated steam further improved the efficiency of steam engines, this time without having serious detrimental effects on their size. The need for mechanical stoking was clear because the “major limitation to the power-output of coal-burning locomotives with firing by hand [was] the amount of coal the firemen [could] shovel.”[[22]](#footnote-22) This limitation was due to the draft of cold air let into the firebox whenever it was opened to shovel coal. Mechanical stoking eliminated this draft and “quadrupled the horsepower production of locomotives.”[[23]](#footnote-23) Mechanical stokers didn’t need to open a door to the firebox to add coal so that the firebox was kept better insulated, and therefore, more of the heat from the burning coal was available to heat the boiler and create steam, rather than being wasted to heat the cold air let in by shoveling coal.

Superheated steam invented by Wilhelm Schmidt in 1900 further improved the efficiency of the steam locomotive. Similar to the compound locomotive, superheated steam was an idea borrowed from advancements in stationary steam engines. Schmidt’s invention passed the steam “through small tubes inserted inside the boiler flues” which “converted the saturated steam to superheated steam.”[[24]](#footnote-24) By superheating the steam, locomotives were able to achieve higher pressures which resulted in greater efficiency and performance. However, although superheated steam brought the pressures inside locomotives closer to those find inside power-generating steam plants, the pressures were still necessarily limited by the construction of locomotives and the efficiency remained far below that of stationary steam engines.

Not all of the improvements were in the areas of performance and efficiency; important changes were also made to improve the safety of steam trains. Perhaps the most important safety improvement was the centrally-controlled air brake, first patented by George Westinghouse in 1869. His invention included “a main compressed air reservoir from which a hose or pipe . . . extended underneath each car, the entire length of the train [connecting] with a break cylinder under each car”[[25]](#footnote-25) Whereas previously a break man would have to run to each car and turn an individual brake handle to apply the brakes on the entire train, with Westinghouse’s invention, the engineer could apply the brakes on the entire train almost instantaneously by operating a single lever in the cab. The air brake was an important step towards safer centrally controlled trains, but it still had its flaws.

Reliance on Westinghouse’s air brake could leave trains without nearly any brakes on a sharp downgrade if a there was a problem in the line connecting the cars to the locomotive. One common problem was ice buildup in the air line. On one occasion Gould was lucky to have “found a nice little marble of ice in the hose connection between the tank of the engine and the first car,” and recalls how “easy it would have been to have started that train rolling down that steep grade. The brakes were all released, and it was a continuous two percent grade for fourteen miles.”[[26]](#footnote-26) This was one of many close calls in which ice had formed in the lines and he only narrowly avoided a runaway train. This danger led to the invention of the automatic brake by Westinghouse in 1872. Westinghouse’s new braking system improved upon the old “adding under each car an auxiliary reservoir” which would automatically set the brakes on its car if “the train line is ruptured” or the pressure is cut off.[[27]](#footnote-27) This invention helped prevent runaway trains and further improved the safety of railroads.

Despite the numerous improvements in steam technology, it still had several severe shortcomings that led to its replacement with electric and diesel-electric trains. The “famous ‘Mallet’ compound type with mechanical stokers and superheaters; the last word of the locomotive builder” came to be the standard steam locomotive.[[28]](#footnote-28) However despite all of these improvements in performance, steam locomotives were still only able to generate a fraction of the power of their electric counterparts. Furthermore, steam engines required extensive maintenance. “Approximately 40 per cent of the average locomotive's time is spent with the mechanical department, caring for running repairs, turning, its monthly boiler wash, and its annual vacation of 20 to 30 days for complete overhauling.”[[29]](#footnote-29) These extensive and frequent maintenance requirements were not only expensive on their own, but they also cost the railway companies precious time during which their locomotives were unavailable to do useful work. The rapid developments in steam locomotive technology even worked against the locomotive, “making an engine obsolete far before the time it was actually worn out in service.”[[30]](#footnote-30) Thus, the costs of steam locomotives were further increased by the need to frequently replace them in favor of the latest technology.

Due to the high costs of steam and the superior performance of electric and diesel-electric engines, the steam locomotive began to be displaced in the earlier twentieth century. At first the steam engines were replaced with “electric locomotives and multiple-unit trains for those sections entering large cities and for suburban service,” while steam engines were retained “as the good old reliable motive power” for the long haul.[[31]](#footnote-31) Electric lines were cheaper to install around cities where power was already plentiful and where relatively short sections of track saw heavy traffic. The more rural western lines would continue to rely on steam for some time, before ultimately transitioning to diesel engines.

At the time of Oliver Evans’ first high-pressure steam-powered carriage there were no railway tracks in the United States for such an engine to run on. Half a century later, the eastern US was crisscrossed by a dense grid of railway lines and the United States government was aspiring towards the first transcontinental railroad, at the time a commercial impossibility. With the completion of numerous transcontinental railroads, the west developed as a result of the increased commerce and the land grants were no longer necessary to prompt construction of new lines. Due to the growing railroad industry, numerous improvements were made to early steam engines. The compound locomotive and improvements to the firebox increased performance at the cost of also increasing size, which made operating newer engines on older tracks difficult. Superheated steam and the mechanical stoker further improved the efficiency of the steam engine, while air brakes improved their safety. However, by the early 1900s, about a century after its introduction, the steam locomotive was beginning to be replaced by electric engines which offered more performance and lower maintenance costs.

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