The London Underground: Driving London to New Possibilities

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The London Underground, or better known as the "Tube," is known as a across the world, but its fascinating construction, history, and successes are often untold. Every day, over three million passengers ride on the London Underground, amounting to 1.37 billion passenger rides annually. Although it is known as the London Underground, only 45% of its railway network is actually underground as many of the outer city lines run above ground. Built, even before electricity, in 1863, the London Underground was the world's first underground railway and now ranks as the fourth largest underground metro system in the world. The Underground originally began as a six kilometer-long track and consisted of only six stations. Most of the tunnels were built and financed by the Metropolitan Railway Company within the first 50 years of construction. Today, the London Underground has expanded to 11 rail lines, 270 stations across 402 kilometers of rail. Utilizing unique architecture and technology, none of the structures of the original stations between Farringdon and Paddington still stand today. However, the construction of these tracks and stations not only gave rise to engineering marvels that saved the lives of millions of Londoners during the World Wars, but it also facilitated London's manufacturing, economy, technology, and social ties in Victorian England, the effects of which reverberated through London and across England. In this paper, I will argue that the presence of the London Underground system precipitated London's rise as a prosperous metropolitan city and financial epicenter.

Planning and Construction

In the early 19th century, London's outer perimeter was expanding and populating quickly, making the ability to travel across the city, especially over the River Thames, exceedingly difficult. Between 1800 and 1850, London's population rose from approximately 1 million people, to 2.5 million. What later became part of the East London Line began as a pathway for pedestrians and possibly carriages to travel across the Thames between the two banks. The importance of the tunnel is much less about the resulting benefits, as it is the methods and techniques used in constructing

what would become the world's first tunnel built below a river or other body of water. Through a series of innovative engineering techniques, the London Underground system became known as one of the great engineering marvels of modern history.

Due to its soil composition of clay, London became an ideal location to develop the first underground tunnels. This soft, yet stable material enabled workers to carve tunnels. However, workers could not build large skyscrapers atop these areas, as the ground could not support the weight of such structures. Therefore, simple geology seems to have predicted the engineering success of the London Underground.[1] Had London sat upon rocky terrain, the London Underground may not be as pervasive and significant to England's prosperity as it is today.[2]

Many daring individuals before had unsuccessfully attempted to tunnel beneath the Thames, until father and son, Marc and Isambard Brunel, developed a new technology capable of the exceedingly difficult project, allowing work to begin in 1825. Their new invention called the Tunneling Shield worked by creating a rectangular shield-large frame- divided into three vertical and 12 horizontal levels.[3] Each of the 36 compartments contained a single worker tasked with digging the soil within their section using a pick and shovel. Once all sections were cleared, the shield would be pushed forward by a system of jacks and the team of bricklayers trailing would build the lining structurally securing the integrity of the tunnel.

Previously unknown geology beneath the Thames caused several financial issues and delays. Consequently, Londoners continued to suffer the pains of commuting. Large clay deposits below the Thames commonly gave way to gravel and sand resulting in frequent flooding of polluted Thames

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[1] Christian Wolmar, *The Subterranean Railway: How the London Underground was built and how it changed the city forever* (London: Atlantic Books, 2004), 133.
[2] Wolmar, *The Subterranean Railway*, 133.
[3] Wolmar, *The Subterranean Railway*, 99.

water and almost drowning Isambard and six other workers.[4] The project was set to cost £179,000, but repeated floods drained the investors' funding forcing work to halt multiple times. Finally, after the government bailed the project out with a loan of £250,000, the tunnel opened in March of 1843. The concept proved valuable for the future, but the tunnel ultimately became a financial disaster. Instead of spending a portion of the funds from the loan to build an access road allowing carriages access and increasing revenue, funds spent elsewhere resulted in only £9,000 of revenue during the first year. Even though the pedestrian tunnel proved to be largely unsuccessful, the concept an underground transportation line manifested.

The idea of an underground railway in the heart of London to reduce street congestion dated back to the 1830s. The mastermind behind the vision of the London Underground was Charles Pearson. A solicitor to the City of London, Pearson worked tirelessly to turn his dream into a reality. Due in part to a lack of funds for the Clerkenwell town-planning scheme, the Metropolitan Railway got permission by the city of London and their plans to build the track approved in 1854. To test the feasibility, in 1855, the Metropolitan Railway built a short test tunnel in Kibblesworth. Kibblesworth shared similar geological properties as London making it a prime location to pilot. The test tunnel was used to develop what would become the London Underground for two years and in 1861, was later filled in. The Kibblesworth tunnel created the concept foundation for the tunnels planned in London to improve gridlock.

At the time, tunnel building remained a new concept, the success of which would determine the expansion and growth of London. Tunnel building required extraordinary amounts of labor-intensive work and in London's case, posed a large social cost by displacing many homes and businesses. The preferred method for tunnel building was a simplistic technique called the 'cut and

[4] Wolmar, *The Subterranean Railway*, 100.

cover, described by Mike Ashworth, Design & Heritage Manager for Transport of London, as a process "to dig a trench, build back the side and roof it over." [5] Technology in the mid 19th century had not yet allowed for tunnel mining. The first railway carriages were powered off steam to reduce the smoke, but the like the stations, were lit by gas burning lamps. Each railway carriage contained a refillable gas filled pouch mounted to the carriage roof that gradually deflated over time as the gas lamps burned. The steam and smoke produced by the engine and lamps respectively required heavy ventilation. Ventilation was produced by 'ventilators,' tunnel chimneys that allowed the smoke and steam to exhaust up and out of the tunnel, while fresh air flowed in filling its place. The demand for proper ventilation and the inability to build tunnels without the 'cut and cover' method meant that all homes and businesses above the path of the underground track were destroyed. Although this method and the resulting wreckage created logistical and financial hurdles for everyone involved, the advantages of the London Underground outweighed these costs.

The Metropolitan Railway did not have space in its budget to compensate the landowners, facing legal action for loss of business or disruption. Unsurprisingly, the home and businesses owners affected as a result of the tunnel construction were not fairly compensated. While some looked for financial compensation, others looked to stop the excavation for safety concerns. To reduce the amount of people affected, the tracks followed as many existing roads as possible.[6] Beneath the existing roads laid many problems as the majority of the city's water, gas, sewage and even electric telegraph lines had to first be diverted before any tunnel construction could begin.[7] An early version of the excavator, powered by steam, increased the efficiency of the project. The machine hoisted dirt dug by groups of navigators in the pits onto faster than prior methods.

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[5] Antony Badsey-Ellis, *London's Lost Tube Schemes*, (Chicago: Capital Transport, 2005), 272.
[6] Wolmar, *The Subterranean Railway*, 35.
[7] Wolmar, *The Subterranean Railway*, 33.

Engineers, designers and marketers had to make the Underground seem less underground in order to appeal to Londoners, one of the first examples of engineering psychology. Many Londoners were skeptical and scared of the idea of being in an enclosed tunnel, so the companies formed multiple press days.[8] These press days hosted journalists and illustrators, during the construction and testing, to show how exposed and similar to existing railways the Underground was. Stations incorporated glass skylights and windows into the roofs and walls of the large open outdoor stations.[9] As one writer for *Illustrated London News* described his preview public journey in 1862,

> Although this curious and unique Metropolitan Railway has been termed underground, or subterranean, for nearly half its length it is open to the light and air of heaven, and where it does pass for various lengths beneath the surface, it is so well lighted and ventilated that the tunnels, instead of being close, dark, damp and offensive, are wide, spacious, clean and luminous, and more like a well-kept street at night, than a subterranean passage through the heart of the metropolis.[10]

Such articles worked well to calm the nerves of the public, but the majority of the positive experiences wrote about preproduction test trials. The unanticipated density of riders led to problems and issues unforeseen in testing. New tunnels to accommodate the increase of passengers required new tunneling techniques.

Building upon many of the same ideas as the father-son built Tunneling Shield, Peter Barlow made one crucial change to the design that furthered the advancement of the technique. Learning from his experience driving down cast-iron cylinders as anchors for the suspension cables on a bridge in Lambeth, Barlow realized a similar method could be used to tunnel horizontally.[11] In 1870, Barlow built the Tower Subway by modifying Brunel's concept and creating a circular shield. The circular shield pattern prevented the soil from collapsing in on itself reducing the likelihood of floods.

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[8] Wolmar, *The Subterranean Railway,* 37.
[9] John Day, *The Story of London's Underground* (London: London Transport, 1963), 26.
[10] "Railway Tunnelling." *The London Journal and Weekly Record of Literature Science, and Art,* no. 35: (1862): 184.
[11] Wolmar, *The Subterranean Railway,* 131.

In addition, Barlow used cast-iron circular supports fit around the rim of the tunnel and connected to one another, instead of bricks, as the shield moved forward.

The cut and cover method no longer became a viable option for expanding or creating tunnels in central London. Existing roads in central London were not straight enough and did not connect enough to justify the cut and cover method.[12] Additionally, the increased density of people and buildings meant more complex networks of sewer, gas, water and electricity lines lay just a few feet beneath the road. Experiments using Brunel's new concept showed that deep tunneling was a possible means of tunneling in the central area, allowing for significantly more opportunity to private investors. The experiment's success sparked investors and developers to expand the underground tunnel system, building new lines and stations practically anywhere with an attraction or heavy foot traffic.

Underground less underground

The London Underground connected Londoners to different parts of the city in a more efficient manner than otherwise available at the time. The London Underground exceeded initial expectations regarding the volume of daily commuters carrying 38,000 people on its opening day. As with any revolutionary marvel, some were hesitant to use the London Underground to ride beneath the earth's surface. After the opening of the track that stretched between Paddington and Farringdon on January 10, 1863, the demand for expansion rose. For the first six months of its operational use to the public, 23,500 people on average used the system daily. Over the next 20 years, the rail system slowly expanded to what would be known in 1884 as the Inner Circle (today's Circle Line), further connecting the different sections of London.

[12] Wolmar, *The Subterranean Railway,* 132.

In order to become a fully usable form of transportation in London, many problems had to first be addressed. Pearson realized that one large problem stood in his way, "finding an engine suitable for use underground. The users' problem was managing to breathe."[13] Passengers complained of too much smoke as many felt ill or claimed to experience asphyxiation. To accommodate the increase of commuters, traditional (nonsteam-condensing) powered locomotives were borrowed to supplement the limited number of condensing locomotives. In addition, as the distance between stations increased, worsened by the expansion of the rails, the condensing tanks, which were designed to cool the water passed through the boilers preventing the release of steam, were far too small.[14] By the time the locomotive had reached the next station, the condensing tanks were at or nearly at the water's boiling point, requiring the tank's safety valves to discharge the built-up steam.[15] The release of steam itself was more of an inconvenience than a public health issue as the ambient temperature rose above the comfortable range. And not just steam was released during the discharge. Along with steam, sulphurous toxic fumes were released in cohesion with the smoke and soot produced by the normal engines. As a result, each passenger breathed a harmful cocktail of chemicals.

Experiments based on the idea of a smokeless locomotive had already been tested by Pearson and his team. Their best attempt used a smokeless engine, called Fowler's Ghost, which used firebricks to produce steam instead of a real flame. Although reliable and successful outside, Fowler's Ghost proved ineffective as the experimental fireless locomotive failed to create enough power for full production use and nearly exploded on its inaugural run due to overheating issues.[16]

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[13] Richard Trench and Ellis Hillman, *London Under London: A Subterranean Guide* (London: John Murray Publishers, 1994), 132.
[14] Day, *The Story of London's Underground,* 58.
[15] Day, *The Story of London's Underground*, 68.
[16] Wolmar, *The Subterranean Railway,* 39.

Despite the numerous complaints of citizens, three separate deaths from the engine's choke-damp (suffocating gas, such as carbon dioxide, often occurring in small underground tunnels) in 1867, and even one case involving a coroner specifically pointing to the tunnel's fumes as the cause of death, the Metropolitan Railway board committee believed no connection between the deaths and tunnel fumes existed and determined that tunnel required no major changes.[17] By the early 1870s after several years of complaints by the public, the Metropolitan Railway installed blowholes between King's Cross and Edgware Road, and removed small sections of glass from the roofs of some stations to improve ventilation. In reality, such changes to improve ventilation and improve the air quality made an unnoticeable difference. The tunnel's air quality did not improve until the replacement of steam-powered locomotives by electric locomotives in 1905. With the improvements in air quality, Londoners felt more compelled to use the rail cars as a mode of transportation.

Brunel's deep tunneling technique was a success too early for its time. The project immediately ran into a problem, not due to the structural integrity, but rather due to the small diameter tunnel hole. The hole could not accommodate the large cables required for trains and could not be easily ventilated.[18] James Greathead, a civil engineer who worked with Barlow on the tunnel shields, improved upon Brunel's design by creating a shield that could remove soil while simultaneously allowing for a layer of cement to be poured, preventing collapse. Electric locomotives allowed tunnels to be built below existing tunnels, buildings, roads and infrastructure. Additionally, electric trains moved quicker, carried more people and cost less to operate than steam powered locomotives. Thus, costs decreased, allowing more workers to afford the daily commute required when living in London's suburbs. To reduce possible complications such as old foundations or basements, the developers continued to follow the paths of existing roads. Following existing

[17] Wolmar, *The Subterranean Railway,* 45.
[18] Day, *The Story of London's Underground*, 112.

roads significantly increased the difficulty of the project as it forced complicated turns and inclines to continue below existing roads and avoid separate tracks.[19] The railways also stayed under roads to avoid paying private parties compensation for disturbance. Without new tunneling techniques such as Greathead's, London would have no way of effectively connecting the city via the heart of London.

Stimulation of economic growth

Nineteenth century London was a small urban city where inhabitants relied upon walking as the major form of transportation. Workers were forced to live close to their workplace because their shifts were long, their wages were low, and there was no form of affordable public transportation. Consequently, what was then considered to be the heart of London was just a few miles long.[20] Thus, the first railway built in London was designed for short distance commute. This railway, the London & Greenwich railway, opened in 1836 as an above ground track.

Later, the railway expanded to include longer distance travel, but these trips were expensive, infeasible for most commuters, and the cause of increased congestion within London.[21] After wealthy railway owners bought more land and displaced London's working-poor from their homes, the resulting overcrowding intensified the need for affordable and efficient public transportation. The answer to the city's need was the London Underground, as it became the efficient and affordable mode of transportation required to advance London and its people.

The London Underground stimulated economic growth in London by expanding city limits allowing the city, businesses and Londoners the space needed to flourish. The expansion of London

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[19] Wolmar, *The Subterranean Railway,* 133.
[20] John Armstrong and Terry Gourvish, "London's Railways—Their Contribution to Solving the Problem of Growth and Expansion*," Japan Railway & Transport Review,* no. 23 (March 2000): 4.
[21] John Armstrong and Terry Gourvish, "London's Railways," 4.

Underground created opportunities for both factory workers and businesses. While factory workers migrated from the slums in downtown London to outside the inner city where housing was cheaper, less crowded and more accessible in the suburbs of London, this created more real estate for new or existing businesses to expand.[22] To further support workers, in the 1860s and 1870s, Railways offered Workmen's fares which were half price early morning return tickets.[23] The Cheap Trains Act of 1883 further promoted affordable train tickets for the working class. As a result, workers began moving away from the center of London in greater numbers, creating working class suburbs. The introduction of "early morning workers' tickets at half price on the railways, brought public transport within the reach of many more working people for the first time and enabled them to live further out from their workplaces in the crowded city centre."[24]

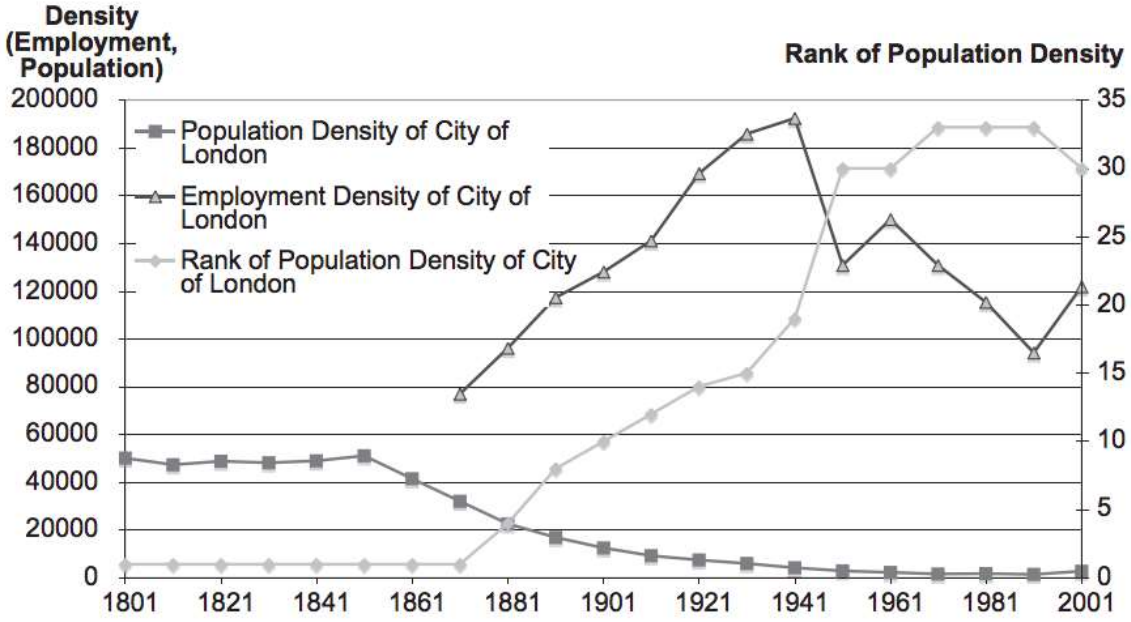

Figure 1 - Graph of Employment vs. Population[25]

[22] John Armstrong and Terry Gourvish, "London's Railways," 4.
[23] London Transport Museum, *Public transport in Victorian London*, (London). [Visited June 12, 2018]
[24] London Transport Museum, *Public transport in Victorian London*, (London). [Visited June 12, 2018]
[25] David Levinson. "Density and Dispersion: The Co-Development of Land use and Rail in London." *Journal of Economic Geography 8*, no. 1 (January 2008): 55-77, https://doi.org/10.1093/jeg/lbm038.

London's outer boundaries extended with the population, expanding from 25 square miles in 1840 to over 100 square miles by 1900.[26] In 1850 to 1910, London's population grew from 2.5 million to over 7 million.[27] Figure 1 shows that in the beginnings of the London Underground, population in the city of London decreased while employment rose. The London Underground expanded city limits which resulted in workers leaving the overcrowded slums within downtown London. As workers left the heart of London, businesses expanded creating more jobs and opportunity inside London. The increased flux of jobs in London attracted people from all around the country seeking work. New workers flooding into London contributed to the fast growth of the Underground system. In the first year of the London Underground's opening, 9.5 million people rode aboard.[28] Within 50 years, the number of yearly passenger journey's increased to over 440 million.[29]

Societal Effect

The London Underground and the heroic male and female operators during the World Wars helped London push through and recover during its toughest times. Additionally, the World Wars helped introduce women into the workforce. Wartime diminished rail services, which created an unpleasant experience for Londoners. Rail services were often cancelled during war time. For services not cancelled, trains became overcrowded with people. Supply shortages forced London to reused retired trains and made maintenance difficult. Consequently, high running costs increased fares.

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[26] B. R. Mitchell and P. Deane, *Abstract of British Historical Statistics* (Cambridge: CUP Archive, 1962), 19.
[27] T. C. Barker and M. Robbins, *A History of London Transport. Vol. I. The Nineteenth Century* (London: Allen & Unwin, 1968), xxviii–xxix.
[28] J.M. Syken. *Underground: How The TUBE Shaped London*, (Fairfax: PDHonline, 2013), 37.
[29] John Armstrong and Terry Gourvish, "London's Railways," 7.

Women held London together during the World Wars. Before the war, women had limited opportunities as they many believed they were not around enough to do 'men's work'.[30] As men left to join the war efforts, women took their place. In the process, changing the public's opinion towards 'women's work'. War gave women new opportunities especially those who worked in transportation. The public supported women transport workers. Transport jobs paid well and gave women a source of pride to be part of the war effort. Women became more respected in the workforce since World War I. After successfully showing their value during World War I, women were hired in all lines of transport work in World War II.

During World War I, all development towards expanding the Underground ceased. The government took control of the entire underground network during the war. First air attacks occurred in 1915 and Londoners protected themselves from attack by escaping to Underground stations. Each night, thousands of Londoners sheltered within the stations during the worst bombings in 1917 and 1918.[31] In the end, during 40 different occurrences, an estimated 4.25 million people took shelter in the Tube.[32] Afterwards, the government realized that competition between lines was very impractical. Thus, in 1921, when the government gave the network of different lines back to the private companies, they required the over 100 companies to consolidate into only four groups: the Southern, the London & North Eastern, the London Midland & Scottish, and the Great Western Railways.[33]

During the Battle of Britain in World War II, London's stations filled with soldiers. London quickly realized above ground shelters did not sufficiently protect its occupants against attack.

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[30] London Transport Museum, *Women and war*. (London). [Visited June 12, 2018]
[31] London Transport Museum, *World War I Air Raids*. (London). [Visited June 12, 2018]
[32] London Transport Museum, *World War I Air Raids*. (London). [Visited June 12, 2018]
[33] John Armstrong and Terry Gourvish, "London's Railways," 7.

Although not its intended purpose, underground stations turned into overcrowded shelters that safely protected Londoners from German bombing raids. Commuters commonly shared the stations with munitions operators and other soldiers. Despite imperfect conditions, the London Underground saved the lives of millions.

The Blitz in September 1940, caught the Underground staff unprepared. Originally, the government discouraged tube sheltering, worried that people staying underground would stop work bringing the city to a standstill. Many Londoners avoided sheltering in the Underground due to insufficient toilets, noise and smell of so many people huddled together. Slowly, Underground shelters became more organized and better equipped with admission tickets, bunk beds, medical aid, chemical toilets and refreshments. Additionally, converted unused tunnels and stations created additional space. For the rest of World War II, the Underground acted as shelter to thousands of Londoners.

Conclusion

The London Underground connected the many neighborhoods of London together in a coherent way. The soft yet stable clay sediment beneath London enabled the engineering marvel tunnel shield invented by Marc and Isambard Brunel and later redesigned by James Greathead. The ability to travel across London in an affordable and reliable way became possible. London expanded into the countryside, farther from the inner city, while still allowing workers to make the daily commute. A mid 19th century account of London's expansion wrote, "it is very difficult now-a-days to say where the suburbs of London come to an end and where the country begins. The railways… have turned the countryside a city."[34] Many of the deep tunnels used today were built using

[34] Anthony Trollope, *The Three Clerks*, (London: Richard Bentley, 1857), 27.

Greathead's method and the cast iron rings can still be seen in some sections. The circular shape these rings created inspired the London Underground's nickname: The Tube. During World War I and II, the Tube system played a vital role protecting the lives of Londoners and establishing women into the workforce. Used to evacuate thousands of woman and kids to the countryside during World War I and as a bomb shelter during Battle of Britain and World War II German bombing raids, the London Underground saved millions of people's lives. Today, it is difficult to imagine what London would be like without the London Underground and its influence on London's manufacturing, economy, technology, and social ties that began during the Victorian era.

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