The orderliness hypothesis

The correlation of rail and housing development in London

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> This extension of the railway system by means of feeder lines means that in many ways the early development of the system can be viewed, not in terms of booms and slumps, but in rational steps. By the end of 1833, three of the five English provincial towns with a population of more than 100,000 had railway links with London under construction; by the end of 1836 only Portsmouth remained among English towns of over 50,000 population without a line authorized; and by the end of 1837 most towns of more than 20,000 inhabitants were on or close to the route of an authorized railway.[1]

The question of whether privately owned networks grow orderly or chaotic is of critical importance for transport planners and others who engage the issue of private ownership or privatisation of infrastructure. Few studies empirically investigate the sequence of network growth in a rigorous way. On the one hand are many largely qualitative studies of particular networks, especially prevalent in the history of railways.[2] On the other are a number of theoretical studies that posit a model of network growth, many of which compare the resulting patterns at equilibrium or some finite point to real or stylised networks but do not compare the sequence of their evolution to actual observation.[3]

In the opening quote Reed suggests what we might dub an 'orderliness hypothesis' to explain the sequence of network growth, positing that places will be connected to the network roughly in order of their population density. (Density is used to control for area.)[4] Garrison and Marble make a similar observation when modelling the deployment of the Irish railway network, observing that nodes connect to the nearest large neighbour.[5] In contrast, Casson argues that the railway network was quite inefficient in Britain, and reliance on state planning could have done much better in terms of final form (as well as presumably the sequence of deployment).[6]

The orderliness hypothesis implies the network follows the population, but the population may also follow the network, so there may be a reinforcing effect, which is difficult to disentangle. This research identifies areas within a metropolitan system, to identify how quickly they connect to the network. While this process may differ from the inter-metropolitan system (or system of cities), there is a great deal of research to suggest the processes that explain the evolution of these two systems may be similar.[7]

This article tests whether stations in London were built in the areas of highest density, measuring the correlation between the density of service (measured as stations per square kilometre) and population density (persons per square kilometre) of the administrative districts (boroughs) in London. There are two major networks to consider, the original surface rail system and the subsequent Underground systems. First, background on the network and land development of London is provided. Definitions for these systems and the source of data are described in the next section. This is followed by measurements of correlation for the two systems, and then discussion of findings. The article concludes with some thoughts about new layers of the transport hierarchy.

Background

Prior to the advent of the steam railway London was a city of just over 1 million people.[8] It was well served by both canals and turnpikes connecting to other parts of Britain.[9] The London & Greenwich Railway was the first of many railways to reach London, the first section opening in 1836 and being completed in 1838, making it possible to reach Greenwich in twelve minutes instead of the hour required by horse-drawn omnibus or steamboat. Famously built on a viaduct, the route was initially paralleled by a tree-lined boulevard that operated as a toll road, serving those unwilling to pay rail fares. However, the toll road was disbanded when the viaduct was widened to enable more frequent services to the densely populated urban core, ultimately growing from two tracks to eleven.[10]

Soon many other railways sought to connect to London. To avoid disruption in the core, a Royal Commission on Railway Termini, appointed in 1846, drew a box around central London and decreed no line should enter the cordon, leading to railway termini being placed on the edges of the central region, and explaining in part why London has no unified railway station.[11] Later (between 1858 and 1860) some penetrations of the box[12] were permitted by Parliament, but most of the City of London remained untouched.[13] While preventing railways from severing the most densely populated part of the city, which would have been expensive for both the railways and the city, it created the need for a connection between the termini to allow transfers. The Metropolitan Railway, a private concern, like all railways of the era, but with some support from the Corporation of the City of London, was approved by Parliament in 1854. It aimed to connect the northern termini (Paddington, Euston, St Pancras, King's Cross,

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and Farringdon, which was later added to the plan) to ease movement for through travellers.

The trends in the City of London were quite different from the rest of London. (Figure 1 displays a map of the boroughs of London.) As shown in Figure 2, the City of London has seen a long trend of depopulation from 1851 (prior to the first Underground line) and for many years saw increasing employment, lending support to the notion that the railways, especially the Underground, enabled decentralisation of residences and concentration of employment.

The Metropolitan Railway opened in January 1863, and was extremely successful. Clearly the market was much larger than inter-line transfers. The company paid dividends throughout its life, though how it could afford to is suspect.[14] The better evidence for its success is in emulation. Many new railway lines were proposed: the 219 London-area railway Bills brought before Parliament during the period 1860–69 totalled 1,420 km (882 miles).[15]

Some of those lines were proposed prior to the opening of the Metropolitan, indicating the smell of success was in the air, though the peak years were between 1863 and 1866, following closely on the heels of the Metropolitan's opening. The most important of these was the Metropolitan District Railway (later called the District Line), which ran just north of the river Thames but south of the Metropolitan, connecting a number of the southern railway
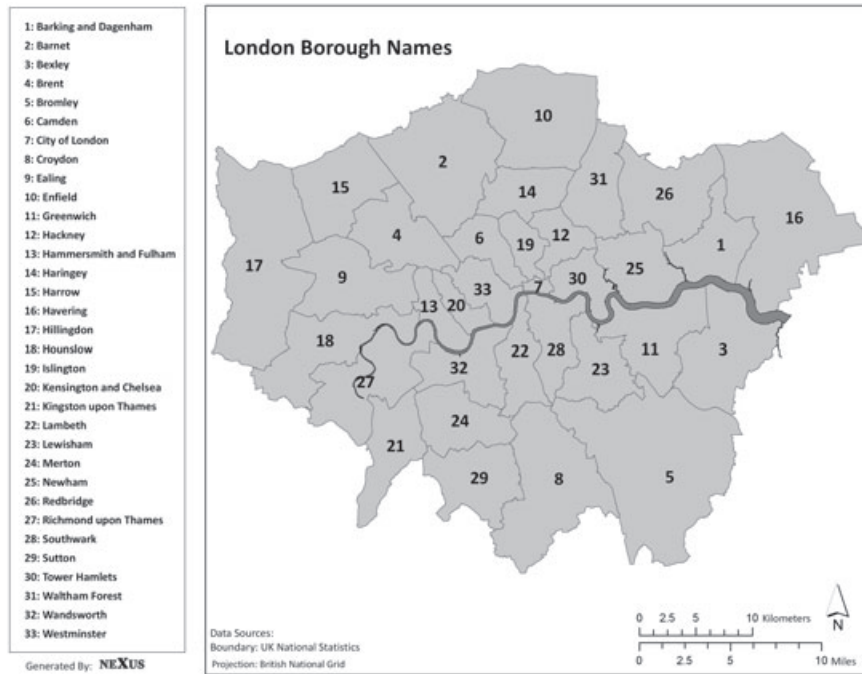
Figure 1   London boroughs by name and location.
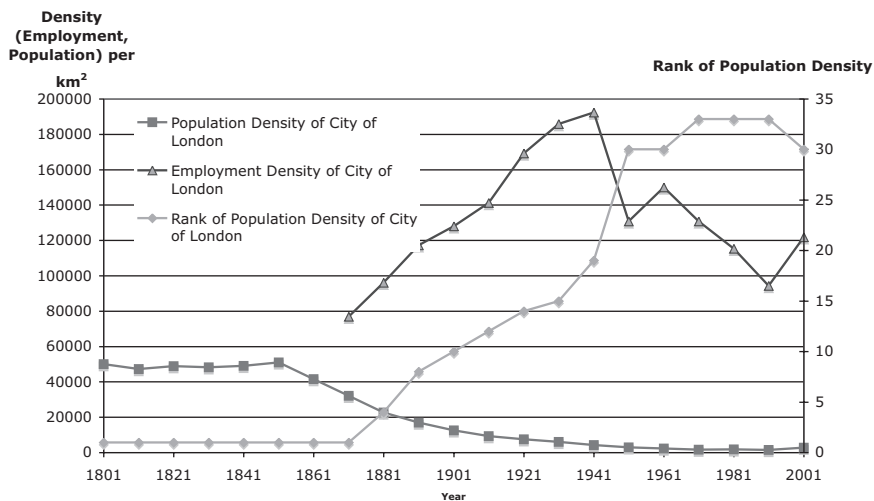
Figure 2 Trends in the City of London.
Source Department of Planning and Transportation, *City of London Workforce Info Census 2001* (London, 2006)

termini. Proposals for what became the Circle Line service linking the Metropolitan and District (roughly inscribing the box described above) were quickly proposed, but the two lines were not connected on both ends until 1884. Both the Metropolitan and District lines were constructed using the cut-and-cover technique. Later lines, from the City & South London Railway (first section opened in 1890) onwards, generally used deep-level tunnelling techniques to avoid disruption of city streets, existing railway lines, and public utilities when they needed to be below grade. Outside the Circle Line, however, the railways could emerge above ground and competed fiercely in some markets, while operating unfettered in others, to provide suburban services. In some cases this involved building new lines, in others it involved acquiring running rights on (or ownership of) existing lines. The development of suburbs was a way to develop traffic for lines that in the city, though profitable, were operating below maximum capacity, and thus maximum profitability.

The suburban extensions of what came to be known as the Underground were much more speculative than those built in the city. Though at-grade suburban lines were less expensive to construct, they also had a lower expectation of revenue. While in the city the demand was present through the high density of existing development, the suburban lines in many cases went through green fields. In contrast with the main-line railways, which had a long-distance market and could add a station on an existing line to test a new short-distance market at minimal cost, an Underground extension required both the line and the station in order to provide a new service to (rather than through) an initially sparsely developed area, what one might dub a 'road to nowhere'.

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The suburban development along the surface railway lines began early. In 1853 the London & North Western Railway (LNWR) advertised in the *Illustrated London News:*

> To persons intending to build houses of a suitable character and of a value of not less than $50 annual rent within two miles of the following stations viz. Harrow, Pinner, Bushey, Watford, Kings Langley, Boxmoor [now Hemel Hemstead] and Tring. A free annual first class pass to one resident of each such house for the following periods—Harrow 11 years, Pinner 13 years, Bushey 16 years, Watford 17 years and the other stations mentioned 21 years.[16]

The LNWR provided an enormous subsidy to the wealthy to build on land the railway did not own. The reasons for this can only be speculated. Was it to prime the pump, since the amount of revenue coming from these houses with an eleven to twenty-one-year free pass, discounted back to the present, would be quite small? Was it to encourage non-work travel, especially by other household members? Or did the railway, or its executives, have a hidden interest in development somehow?

Two decades later the suburbs had begun to take shape. 'About the Barnet station has sprung up within the last few years one of those new half-finished railway villages which we have come to look on as almost a necessary adjunct to every station within a moderate distance of London.'[17] The network in the north-west quadrant of London was the least dense with surface railway lines. Not surprisingly, those were the unharvested suburban pastures that attracted the most attention from the Underground railways.

The powers to develop land varied. Section 127–8 of the Land Clauses Consolidation Act of 1845 required that, within ten years, railways must dispose of land not required for the projects identified in the parliamentary Act describing and authorising the railway. The Metropolitan Railway Acts of 1868 and 1873, however, allowed the Metropolitan to hold on to such land for a longer period of time, putting the Metropolitan into the development business in a way that other railways were not permitted.[18] The lack of effort to get similar provisions inserted into the Act of other railways suggests those railways did not wish to enter the development business.

The Metropolitan Railway acquired surplus land as it acquired right-of-way. In large part, this was the acquisition of whole parcels when sellers did not want their property bisected by the railway. Unlike other railways in the United Kingdom, however, the Metropolitan had parliamentary authority to develop that land, and did not sell surplus land as quickly as possible. The consequence of this was the development of Metro-land, and the ability to pay higher dividends due to its real estate division than other Underground railways were able to. That said, other railways, along with the Metropolitan, did work with developers to obtain subsidies for building stations near their new developments and promising to run services.

When Charles Tyson Yerkes—an American-born railway magnate who acquired a number of the deep-level Tube lines and the Metropolitan

District Railway, as well as other transport properties—was investigating whether he should invest in the proposed Hampstead (now Northern) line in 1900, the following came to pass.

> When they came to Golders Green, Lauderbeck [agent for Charles Yerkes] stopped and told Dalrymple-Hay [British civil engineer] that here was the proper site for the terminus, meeting protests about the absence of houses by pointing out that in the USA, railways were built and the people followed. After visiting the site himself Yerkes asked, 'Where's London?' and on being shown, turned to his companion with the words 'Davis, I'll make this railway.'[19]
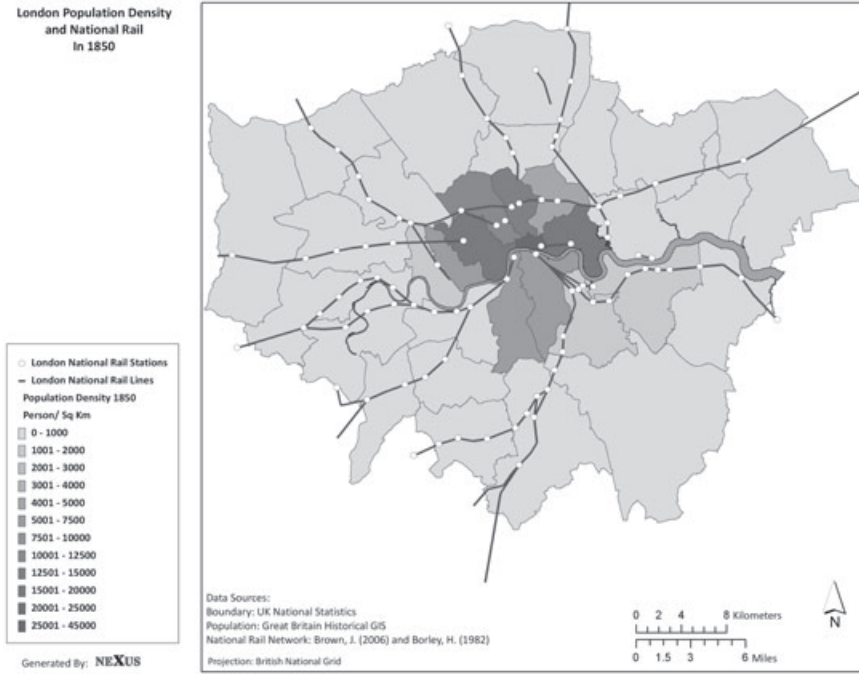
White writes:

> The [Hampstead, later Northern] line emerged into daylight to terminate in the fields bordering the Finchley Road. Most people were unimpressed by the wisdom of this move, but it is said a syndicate had already been formed to buy up the turnip fields before the announcement of the new line had affected land values. Thus at Golders Green first began the typical pattern of twentieth-century suburban development, the arrival of an electric railway in some untouched rural area, soaring land values, semi-detached villas and chain stores.[20]

Despite this activity, the sum of Metro-land developments created directly by the Metropolitan Railway and its subsidiaries amounts to only about 15,000 houses on about 2,200 acres.[21] But when considering the accompanying private developments that took advantage of the accessibility created by the railways, and thus gave traffic to the railways, the change was enormous.[22] The change is illustrated in Figures 3–6, which show the development of both the railway networks and the population density of London from 1850 to 2000 at fifty-year intervals.

Ultimately the co-development of suburbs and Underground lines came to a halt with the 1948 designation of a Green Belt around London.[23] This resulted in the cancellation of proposed line extensions, and hemmed in the Underground-served suburbs. Later suburban developments jumped the Green Belt, but these were to be served by automobile, bus, or surface rail. The next section quantitatively examines the extent to which rail and residential suburbs co-developed in an orderly fashion, from the advent of rail through the imposition of the Green Belt and the rise of the automobile, and whether that order was maintained.

Data, definitions and analysis

Definitions in this area are not straightforward. At present there is an Underground system operated by Transport for London (with infrastructure provided by private firms under long-term concessions) and a surface rail system whose tracks are managed by Network Rail, with trains operated by

London Population Density
and National Rail
In 1850

London National Rail Stations
London National Rail Lines
Population Density 1850
Person/ Sq Km
0 - 1000
1001 - 2000
2001 - 3000
3001 - 4000
4001 - 5000
5001 - 7500
7501 - 10000
10001 - 12500
12501 - 15000
15001 - 20000
20001 - 25000
25001 - 45000

Generated By: NEXUS

Data Sources:
Boundary: UK National Statistics
Population: Great Britain Historical GIS
National Rail Network: Brown, J. (2006) and Borley, H. (1982)
Projection: British National Grid

0 2 4   8 Kilometers
0 1.5 3   6 Miles

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Figure 3   London railways and population density, 1850.

London Population Density,
London Underground,
and National Rail
In 1900

London National Rail Stations
London National Rail Lines
London Underground
Bakerloo
Central
Circle
District
East London
Hammersmith & City
Jubilee
Metropolitan
Northern
Piccadilly
Victoria
Waterloo & City
Population Density 1900
Person/ Sq Km
0 - 1000
1001 - 2000
2001 - 3000
3001 - 4000
4001 - 5000
5001 - 7500
7501 - 10000
10001 - 12500
12501 - 15000
15001 - 20000
20001 - 25000
25001 - 45000

Generated By: NEXUS

Data Sources:
Boundary: UK National Statistics
Population: Great Britain Historical GIS
National Rail Network: Brown, J. (2006) and Borley, H. (1982)
Underground Network: Sanders, E. (2006) and Rose, D. (2000)
Projection: British National Grid

0 2.5 5   10 Kilometers
0 2.5 5   10 Miles

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Figure 4   London railways and population density, 1900.

**London Population Density,
London Underground,
and National Rail
In 1950**

○ London National Rail Stations
— London National Rail Lines
London Underground
■ Bakerloo
— Central
▭ Circle
— District
— East London
— Hammersmith & City
— Jubilee
— Metropolitan
— Northern
— Piccadilly
— Victoria
— Waterloo & City
Population Density 1950
Person/ Sq Km
▫ 0 - 1000
▫ 1001 - 2000
▫ 2001 - 3000
▫ 3001 - 4000
▫ 4001 - 5000
▫ 5001 - 7500
▫ 7501 - 10000
▪ 10001 - 12500
▪ 12501 - 15000
▪ 15001 - 20000
▪ 20001 - 25000
▪ 25001 - 45000

Generated By: NEXUS

Data Sources:
Boundary: UK National Statistics
Population: Great Britain Historical GIS
National Rail Network: Brown, J. (2006) and Borley, H. (1982)
Underground Network: Sanders, E. (2006) and Rose, D. (2000)
Projection: British National Grid

Figure 5   London railways and population density, 1950.

**London Population Density,
London Underground, National Rail,
and Docklands Light Railway
In 2000**

○ London National Rail Stations
— London National Rail Lines
London Underground
■ Bakerloo
— Central
▭ Circle
— District
— East London
— Hammersmith & City
— Jubilee
— Metropolitan
— Northern
— Piccadilly
— Victoria
— Waterloo & City
○ Docklands Light Railway Stations
— Docklands Light Railway Lines
Population Density 2000
Person/ Sq Km
▫ 0 - 1000
▫ 1001 - 2000
▫ 2001 - 3000
▫ 3001 - 4000
▫ 4001 - 5000
▫ 5001 - 7500
▫ 7501 - 10000
▪ 10001 - 12500
▪ 12501 - 15000
▪ 15001 - 20000
▪ 20001 - 25000
▪ 25001 - 45000

Generated By: NEXUS

Data Sources:
Boundary: UK National Statistics
Population: Great Britain Historical GIS
National Rail Network: Brown, J. (2006) and Borley, H. (1982)
Underground Network: Sanders, E. (2006) and Rose, D. (2000)
Docklands Light Railway Network: Sanders, E. (2006) and TFL (2006)
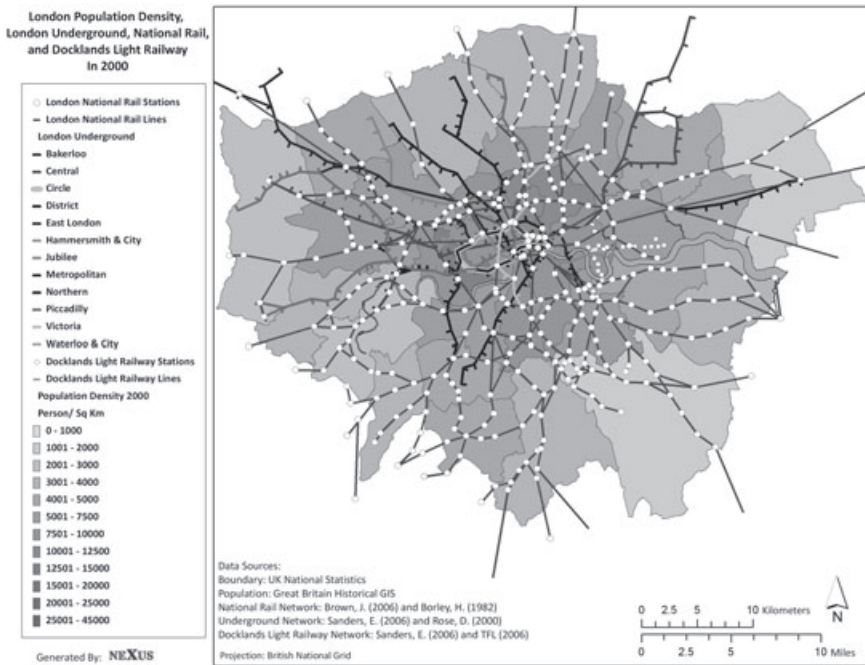Projection: British National Grid

Figure 6   London railways and population density, 2000.

private companies under franchise agreements. Some stations (especially transfer stations) are managed by parties in one system but have services from the other. Much of the 'Underground' system operates above ground, and some is elevated, while some of the 'surface' system operates beneath or above the surface. This article defines the surface rail system as all currently existing London-area heavy-rail stations and lines that are not part of the 2006 Underground system, excluding Croydon Tramlink and Docklands Light Railway. Some services have historically been transferred from one system to another; it is their current ownership that is used to define which system they are in.

Data for the Underground dates of station openings and closings were obtained from Rose.[24] Data for surface rail dates were from Borley.[25] A variety of sources were used to place stations in current administrative districts (boroughs).

Population data were obtained for the thirty-three current administrative districts (thirty-two boroughs and the City of London, collectively called boroughs throughout the article) of London going back to the 1801 census.[26] Censuses that had been conducted before the current boundaries were established in 1965 had been recoded to give totals for the current areas. Thus we have twenty-one points in time for thirty-three areas, giving 693 population data points. Ideally a similar procedure would be undertaken for employment. However, the employment data that are available in the nineteenth century are only by place of residence, which make them largely unusable to analyse transport systems, where we are interested in both stations that serve as commuting origins and those that serve as destinations. It was not until 1921 that the UK census asked questions about place of work, and these data are not yet digitised. Estimates for the City of London are discussed below.[27]

To test the proposed hypothesis, the Pearson product–moment correlation (r) is used. An $r = 1$ (or $r = -1$) indicates a perfect positive (negative) correlation; an $r = 0$ indicates no correlation.[28]

Looking first at surface rail service in London, it took several decades for the rail system to correlate well with population density, as the rail system was largely built from the outside in, while the Underground system was built from the inside out. As shown in Figure 7, from a correlation between population density and surface rail station density of 0.56 in 1841 (only a few years after rail first entered what is now London in 1836 in Greenwich, Lewisham, and Southwark), it already served twenty-three boroughs (missing the present day boroughs of Islington, Lambeth, Richmond, Waltham Forest, Hounslow, Brent, Sutton, Barnet, Bexley, and Barking and Dagenham). By the census year of 1851 thirty-one boroughs were served, and by 1871 all thirty-three boroughs had at least one station.

At its peak in 1871 the correlation was 0.89. This soon began to drop as the population moved but the train stations and lines largely stayed put. The greatest mismatch occurred in 1951 when the correlation was down to 0.34

**Correlation between Population Density Rank and Train Station Density Rank
of London Boroughs (Local Administrations)**
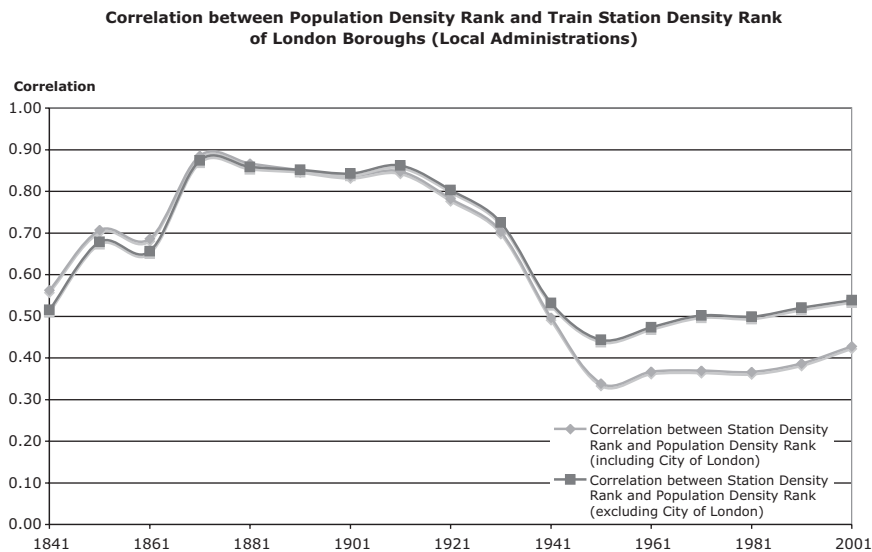
Figure 7 Correlation between population density rank and train station density rank of local administrative districts, 1841.

(including the City of London) or 0.44 (excluding the City). The City of London is a major confounding factor, depopulating over time as it gained employment.

In 1863 the first Underground railway, the Metropolitan Railway, was opened. Initially the Metropolitan served the boroughs of Westminster, Islington, and Camden (the third, fourth, sixth densest boroughs in 1871). In 1864 Hammersmith and Fulham (rank 10) and Kensington and Chelsea (rank 5) were added. In 1865 the City of London, then the densest borough, joined what came to be known as the London Underground system. In 1867 Barnet (rank 27) and Haringey (rank 15) added stations on the Great Northern Railway that were ultimately incorporated into the London Underground system in 1939. For consistency they are included here but illustrate the complexity of making a clean distinction between the systems.

Figure 3 indicates there is a fairly strong correlation between rank of population density and rank of Underground station density. Including the City of London, the correlation starts at 0.77 for the first eight boroughs (current administrative districts, including the City of London and City of Westminster) in 1871, the first census year after the Underground was first deployed, to 0.48 in 2001. However, the City of London itself greatly skews the results, as the Underground enabled it to depopulate and become an enormous centre of employment. As shown in its rank in Figure 1, from having the highest population density of all the thirty-three boroughs in 1871 (at over 32,000 persons per square kilometre), it drops remarkably to the lowest population density of all boroughs a century later (a density of
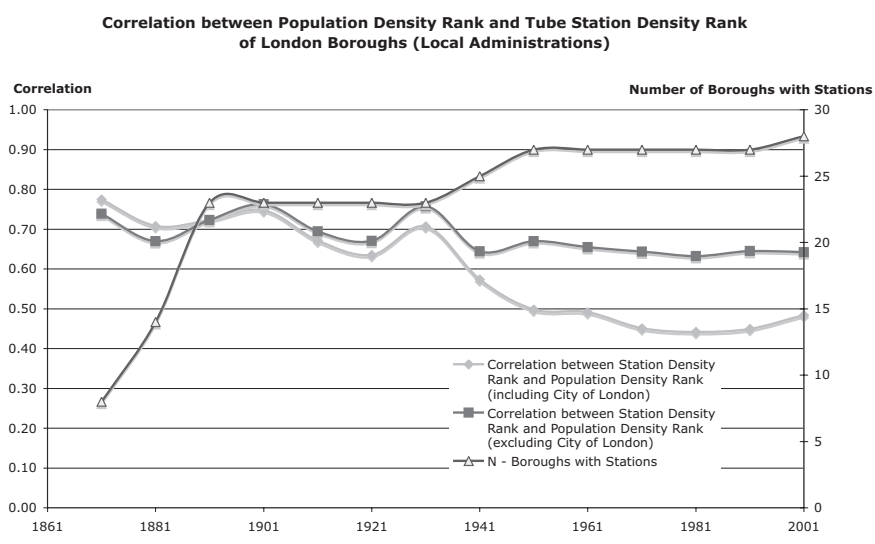
only 1,663 persons per square kilometre). While there are no accurate data on employment dating back to the nineteenth century, as the census did not ask questions about place of work until 1921, estimates for the City of London are reproduced in Figure 1.

Though employment growth and depopulation may have been factors in some other central boroughs, none was so precipitous as the City of London. So running the same test but excluding the City gives us a stronger statistical correlation between population and Underground stations, changing from 0.77 in 1871 to 0.64 in 2001. This drop still indicates an increasing misfit between the location of stations and the distribution of population, which may tell the story of under-investment in the later part of the twentieth century and the concomitant rise of alternative modes (trams and later motor buses and the automobile) serving the farther reaches of Greater London.

Still, there are some surprising mismatches between population and Underground stations. As Table 1 shows, Tower Hamlets, just to the east of the City of London, did not get Underground service until 1882, almost twenty years after the introduction of the technology, despite having the second highest population density and being very close to the centre. Hackney did not get a station (Manor House) until 1932 (and that is near the edge of the borough) despite having the fourth highest population density at the time. Manor House remains the only station in Hackney (although the proposed extensions to the East London Line may rectify that). The reasons for these mismatches can only be speculated, but factors may include the relatively lower incomes associated with the East End of London than the west, and thus the relatively higher use of less pricey surface transport modes (buses and trams).

Even today, several of the thirty-three boroughs remain without any Underground service; their population density ranks are given in parentheses (1871 rank, 2001 rank): Bexley (28, 27), Bromley (29, 33), Croydon (20, 24), Kingston upon Thames (19, 23), and Sutton (26, 22). It should be noted that all are on the edge of Greater London, all have commuter rail service, and since 2000 Croydon has Tramlink, a partially grade separated light rail service connecting to the Underground and surface rail systems at Wimbledon.

This uneven distribution of service does create some political problems for the agencies administering the London Underground. Attempts to change the basis of revenue away from fares and towards other sources (e.g. the Fares Fair campaign of the Greater London Council in the early 1980s, which tried to lower fares and increase the 'rates' (tax) paid by households) faced political opposition on the issue that some boroughs remain without, or with only poor, service and do not wish to cross-subsidise other boroughs with better service.[29] Many jurisdictions, especially in the United States, which rely on public finance, do end up with a large amount of public transit service in lower-density suburban areas to satisfy the political logic that

**Correlation between Population Density Rank and Tube Station Density Rank
of London Boroughs (Local Administrations)**

Figure 8 Correlations between population density rank and Underground station density rank of London administrative districts, 1950.

requires spatially extensive service to achieve the political coalition required for the subsidies to provide service where it is most needed.[30]

Discussion and conclusion

This article examined the correlations between the extent of the rail network in London with population density. The rail network initially went where the people were, and then developed new lines (and opened new stations on existing lines) in green fields that were subsequently developed and populated. With the advent of competing modes (tram, motor bus, car) and reduced investment in rail in lower-density areas the strong correlation between rail network location and population diminished over time.

While there is clearly some order to the deployment, and by and large the densest areas got service before the less dense areas, there was still a great deal of inequity and unevenness in the process. Ideally, service and demand would track very closely. Use of station density and population density as surrogates for service and demand is an approximation, but informs us of the degree to which there was a mismatch.

What might cause the correlation to be imperfect? A number of possibilities emerge. First, entrepreneurs built infrastructure based on anticipated profits. Profit is defined in economic terms as revenue minus cost. While revenue may be roughly proportional to population density (for commuting origins) or employment density (for commuting destinations), costs rise with density. Building underground is much more expensive than building on the surface, and generally is undertaken only if the lowered cost of land

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acquisition outweighs the higher cost of construction. The first Underground lines were built using the 'cut and cover' technique. Later Underground lines had to avoid conflict with the first, and were built deeper, using other tunnelling methods that were more expensive from a tunnelling perspective but less expensive after considering the costs of utility relocation and street disruption. After noting those differences, costs are not uniform across the region.

Several factors may be responsible for why the south of the Thames region differs from the north in terms of network development. London is in the south of England; railways south of London would have a much shorter market to begin with, and would be quicker to see commuting as part of their business rather than a distraction from longer-distance traffic. The territory south of the river Thames has geological characteristics that are not as conducive to subsurface construction as north of the river, and as a result most lines south of the Thames were above ground. Perhaps the railways south of the Thames were more entrepreneurial in serving local customers as opposed to viewing themselves as main-line railways, as the stations north of London did. As of 1854:

> Some, like the [south London] lines to Blackwall and Greenwich, already provide a frequent service; the London & Croydon had given careful thought to the siting of its six suburban stations. But the trunk lines out of [north London stations] King's Cross, Euston and Paddington hardly noticed the suburban traveller at all. Each passenger at Euston in 1846 had made an average journey of sixty-four miles.[31]

And this was true elsewhere in England as well.

There was significant competition for many years between the London Chatham & Dover Railway (LCDR) and the South Eastern Railway (SER), as well as between the South Eastern and the London Brighton & South Coast Railway (LBSCR) to serve the same markets. This competition increased service area coverage (and to a small extent overall service frequency) for customers, and the number of available stations, at the cost of railway profits. The LCDR and SER entered a working union in 1899, forming the South Eastern & Chatham Railway (SECR). The LBSCR remained independent until the 1923 amalgamation with the London & South Western and the SECR to form the Southern Railway. Furthermore, in the 1920s the Southern came to an agreement with the Underground Group that 'no future application in parliament for an extension of [an Underground Group] railway within the Southern Railway's area and within two miles of an existing SR line should be made without giving twelve months' notice to the Southern Railway'.[32] The Southern was also the railway that most quickly adapted to electrification, starting in 1931, enabling a higher level of service than the steam-powered lines could produce.[33]

Competition between Underground and surface rail needs to be accounted for. Areas with surface rail service connecting to the City of London did

not have as great a demand for new Underground lines as areas with poor service. Hence the area with the fewest surface lines (the north-west) attracted the most Underground.

Looking forward, there are several ways to increase the correlation between population density and rail service: build new stations where the people are (which tends to be expensive, as building stations and railways in built-up areas is much more difficult than building them in green fields); remove stations where the people aren't (which is fairly inexpensive but politically unpopular); limit service so that trains skip low-volume stations; or move people to where the stations are (which is difficult unless there is available (re-) developable land). All of these strategies have been and continue to be tried. When the distribution of population is taken as a given (as in the early years of the development of the rail and Underground systems), stations try to match people. Once that is done, the networks may try to expand their market by building in green fields and promoting development. Metro-land and other suburban developments promoted by the railroads are an example of trying to induce the population to move to match the network. Several periods of closing stations, especially under-used or poorly located surface rail stations, have occurred. World War I and World War II were precipitating events, as was rail rationalisation under the 'Beeching axe' in the 1960s (which did not affect Greater London as much as other areas of England, though the Great Central Railway was closed north of Aylesbury).

In London, current examples of these strategies are Crossrail, to provide new capacity in the densest areas of London (and connect with existing suburban lines to the east and west); Docklands Light Rail (DLR) and Jubilee Line extension, aiming to re-energise the now obsolete port terminals of east London with new service running, in the case of DLR, largely on existing rights of way; and continued rationalisations of selected lines and stations to reduce costs and improve service for existing customers. The growing incorporation of Calais into the London commuter shed is associated with the construction of the Channel tunnel and high-speed lines into London.

Retro-fitting developed areas with rail is expensive, as the early promoters of the London Underground discovered in the 1860s, the builders of the deep-level Tube lines rediscovered in the first decade of the twentieth century, and modern-day builders of projects such as the Boston's Big Dig and the Channel tunnel have discovered yet again.[34]

Though this article examined London, the issues are common throughout large cities that grew up with fixed rail infrastructure and faced changes in transport and building technology.[35] Roads, and the modes that use them (bus and car in particular), provide a great deal more flexibility in travel and location than does fixed rail service, enabling people to move to lower-density areas with lower housing costs. As people moved from the crowded Victorian city to the Edwardian (and later) suburbs they lowered the density at the centre and raised it at the edge. However, since the edge has so much

more area than the centre, the density drop in the centre was of a much greater magnitude than the rise of density in the suburbs. Once the user's time and the cost of competing modes became competitive with (or superior to) rail in the early twentieth century, rail lost market share, making it more difficult to build new lines and chase the ever mobile passenger.

After a long decline, rail's market share has increased in London since the 1980s. Restoring land use to a density and pattern where rail could regain dominance is an unlikely future. Selected developments could increase density in a few rail-oriented locations and new lines could be built in a limited number of high-density un(der)-served corridors, communications technologies have decreased the pressure for the physical proximity that made the City of London (and other downtowns) what they were at rail's zenith. With less need for new hyper-dense commercial agglomerations, there is less need for fixed-rail transport to serve them, a few exceptions such as the Docklands noted. This is not to say rail will not remain important in selected places, particularly with congestion, environmental, and parking charges making car driving increasingly expensive. Connecting people to the centre of London will continue to be a market dominated by trains, and Crossrail should be a significant part of that in coming decades.

Notes

1 M. C. Reed, *Investment in Railways in Britain*, *1820–1844* (Oxford, 1975), p. 22.
2 E.g. T. C. Barker and M. Robbins, *A History of London Transport* I, *The Nineteenth Century* (London, 1963); T. C. Barker and M. Robbins, *A History of London Transport* II, *The Twentieth Century to 1970* (London, 1974); C. Barman, *The Man who built London Transport: a Biography of Frank Pick* (London, 1979); H. P. White, *A Regional History of the Railways of Great Britain* III, *Greater London* (London, 1963).
3 Many of these are reviewed in David Levinson and Bhanu Yerra, 'Self-organization of surface transportation networks', *Transportation Science* 40, 2 (2006), 179–88.
4 Zipf's law, or the rank size rule, suggests that the second largest city is half the size of the largest, and the third largest city is one-third the size, and so on. This distribution of city sizes has been found in a number of cases, and there are a few theories as to why it might be the case, for instance Xavier Gabaix, 'Zipf's law for cities: an explanation', *Quarterly Journal of Economics*, August (1999), 739–67. Zipf's law would provide economic support for connecting the largest places first (if costs were equal), as those places are notably larger than smaller places.
5 William L. Garrison, and Duane F. Marble, *A Prolegomenon to the Forecasting of Transportation Development: Technical Report* (Washington DC, 1962).
6 Mark Casson, *The Evolution of the British Railway Network*, *1825–1914*, ESRC report R000239586, http://www.esrcsocietytoday.ac.uk/ESRCInfoCentre/ViewAwardPage. aspx?AwardId=1782 (accessed 6 February 2007).
7 Michael Batty and Paul Longley, *Fractal Cities: a Geometry of Form and Function* (London, 1994).
8 According to the 1831 UK census, the area that is now London had 1.099 million people living there. Vision of Britain, *A Vision of Britain through Time* (London, 2006), http:// www.visionofbritain.org.uk/index.jsp (accessed October 2006).
9 Dan Bogart, 'Neighbors, networks, and the development of transport systems: explaining the diffusion of turnpike trusts in eighteenth-century England', *Journal of Urban Economics* 61 (2007), 238–62.
10 Edwin Course, *London Railways* (London, 1962).
11 S. R. Hoyle, 'The first battle for London: a case study of the Royal Commission on Metropolitan Termini', *London Journal* 8 (1982), 140–55.

12 The 'box' keeping railway lines out of the centre of London was penetrated at Victoria, Charing Cross, and the extension from Blackfriars to Farringdon.
13 The City of London, the original centre of Greater London, is now an administrative district within London.
14 Accounting in the early years of the Metropolitan Railway, especially prior to the Regulation of Railways Act of 1868, was a bit dodgy, and dividends were reportedly paid out of capital. To quote Jackson in *London's Metropolitan Railway*, p. 38, describing the era of 1865, 'It was . . . a house of cards, a precarious game in which the level of dividend was kept up at all costs, by finding money from somewhere, with no regard to sound accounting or financial rectitude.'
15 Jack Simmons, *The Railway in England and Wales, 1830–1914* I, *The System and its Working* (Leicester, 1978), p. 121. This large number of Bills involves duplication both within firms—lines proposed one year and not approved might be proposed again with minor modifications—and between companies—substantially the same line proposed by more than one company.
16 Course, *London Railways*, p. 198.
17 J. Thorn, *Handbook to the Environs of London* (1876), p. 31, quoted in Simmons, *The Railway*, p. 127.
18 Alan A. Jackson, *London's Metropolitan Railway* (Newton Abbot, 1986), especially chapter 9.
19 Desmond Croome and Alan A. Jackson, *Rails through the Clay* (London, 1993), pp. 4, 45.
20 H. P. White, *A Regional History of the Railways of Great Britain* III, *Greater London* (London, 1963), p. 100.
21 Clive Foxell, *Rails to Metro-land* (Chesham, 2005), p. 105.
22 Alan A. Jackson, *London's Metro-land* (London, 2006).
23 Dennis Edwards, *London's Underground Suburbs*, 2nd edn (London, 1986), p. 106.
24 Douglas Rose, *London Underground Diagrammatic History*, 7th edn (London, 1999).
25 H. V. Borley, *Chronology of London Railways* (Oakham, 1982).
26 Vision of Britain, *A Vision of Britain through Time* (London, 2006).
27 Future analysis should attempt to obtain the density of opportunities (e.g. employment) to examine the strength of correlation of station location with the non-home end of trips. It may be possible through use of historical GIS data to develop surrogate indicators for employment or commercial activity.
28 The Pearson product–moment correlation is given by:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 (y - \bar{y})^2}}$$

where *x* and *y* are the two variables to be correlated and x̄ and ȳ are the expected values of those two variables.
29 Dave Wetzel, Vice-chair of Transport for London, personal conversation, November 2006.
30 Brian Taylor, 'Unjust equity: an examination of California's Transportation Development Act', *Transportation Research Record* 1297 (1991), 85–92.
31 Simmons, *The Railway*, p. 50.
32 Croome and Jackson, *Rails through the Clay*, p. 150.
33 White, *A Regional History of the Railways of Great Britain*.
34 Bent Flyvbjerg, Nils Bruselius and Werner Rothengatter, *Megaprojects and Risk: an Anatomy of Ambition* (Cambridge, 2003).
35 Paolo Capuzzo, 'Between politics and technology: transport as a factor of mass suburbanisation in Europe, 1890–1939', in C. Divall and W. Bond (eds), *Suburbanising the Masses: Public Transport and Urban Development in Historical Perspective* (Aldershot, 2003), pp. 23–48.

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