Volterra

Transport Accessibility and Development Density

A report by Volterra Partners, May 2017

Volterra

1 Introduction

The correlation between transport accessibility and employment density (jobs/ha) has been used by Volterra in the past to show how development, in terms of jobs per hectare, might respond to new transport. Using updated generalized time matrices, models were created for the years 2007, 2011 and 2015, with each producing a strong statistical relationship between Accessibility and Employment Density. Data on GT matrices, population and jobs have been supplied by TfL, and are all taken from the LTS model.

Using models across a number of years has added a time-series dimension to a previously static model. An issue when dealing with the time-series element is that the time period is relatively short in development terms. Between 2007 and 2015 there were few improvements to the transport network but large increases in population and employment. The ability of development to respond to transport changes over a short time period is also fairly low.

2 The Accessibility: Density relationship

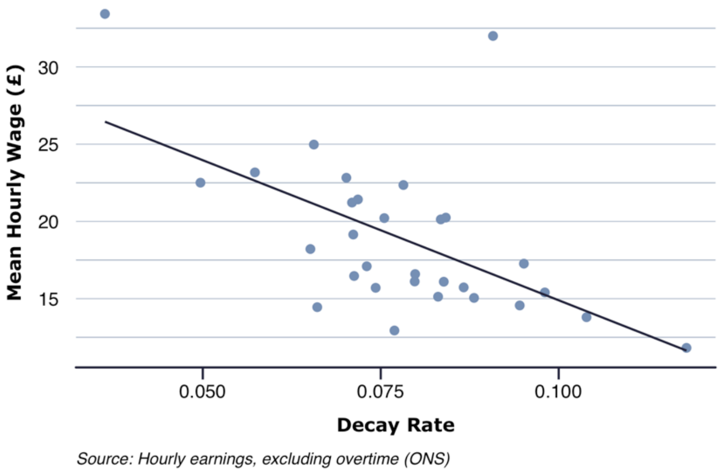
The accessibility measure is calculated using a "gravity-style" model. The accessibility to population of each zone is found by measuring the Generalised Time (GT)[1] to a destination zone from all other origin zones. The resulting measure is weighted by the population in each of the origin zones, such that the zones with a higher number of residents are more important than zones with fewer residents. The measure calculates accessibility using Public Transport trips only, as this was found to be the most reliable estimator of employment densities for Greater London, compared to using Highway trips or a mix of the two.

There are 878 zones from the Rail Plan model within the GLA boundary. For each zone, Employment and population is modelled, along with GT values for each origin-destination combination, allowing the accessibility measure to be derived.

Within the accessibility measure, a "decay rate" is applied, which captures the relationship between the GT of a trip and the proportion of people who are willing to make that trip. A high decay rate shows that the proportion of trips from a given zone to various destinations falls rapidly as GT increases – people have a strong preference for shorter trips. It has also been identified that people are prepared to travel long distances to certain, unique, destinations. That is, the decay rate for trips to high paid jobs in the city is extremely low; distance does not deter people from making long trips to these locations (the two notable exceptions, and outliers from the trend in Figure 1, are the City of London and Tower Hamlets. Tower Hamlets has a far higher wage than would be expected given its relatively high decay rate; the City has the lowest decay rate but still commands a higher wage than is expected.)

[1] Generalised Time (GT) is a measure whereby clock time is adjusted to take account of behavioural factors. For example, research shows that passengers dislike walking more than they dislike sitting, so walking and sitting times are weighted as such.

Figure 1: Decay rates are low for boroughs with a high hourly wage



When applied to the model, this decay rate is used to give higher GTs an exponentially decreasing weight in the model, and lower GTs a higher weighting. This captures people's non-linear preferences for shorter GTs.

With this in mind, Volterra tried three approaches to test the significance of the distance decay parameter. The accessibility calculation in Equation 1 was applied with:

- a static decay rate applied to the GT between every zone;
- a varying decay rate specific to each origin zone; and,
- without any decay rate.

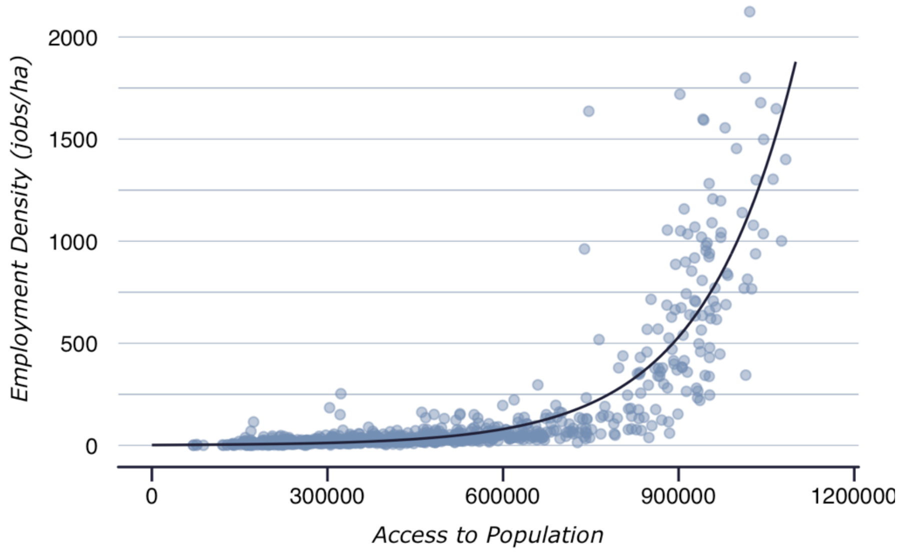
Equation 1: $$Accessibility = \sum_{k=0}^{n} Population \cdot e^{-(Decay\ Rate)\cdot Generalised\ Time}$$

Having tested the goodness of fit of the resulting relationships between each accessibility measure and employment density, it was found that a single decay rate for a given year was the most appropriate. The full process and results are provided in Appendix 3.

3 The Cross-Sectional Relationship

The Accessibility: Density relationship is a cross-sectional relationship. It aims to show the correlation between employment density and the level of access to labour. Zones below the curve may have unmet development potential, and zones above the curve are more likely to have their growth constrained by a lack of transport capacity or accessibility.

Figure 2: The Accessibility: Density relationship for 2011

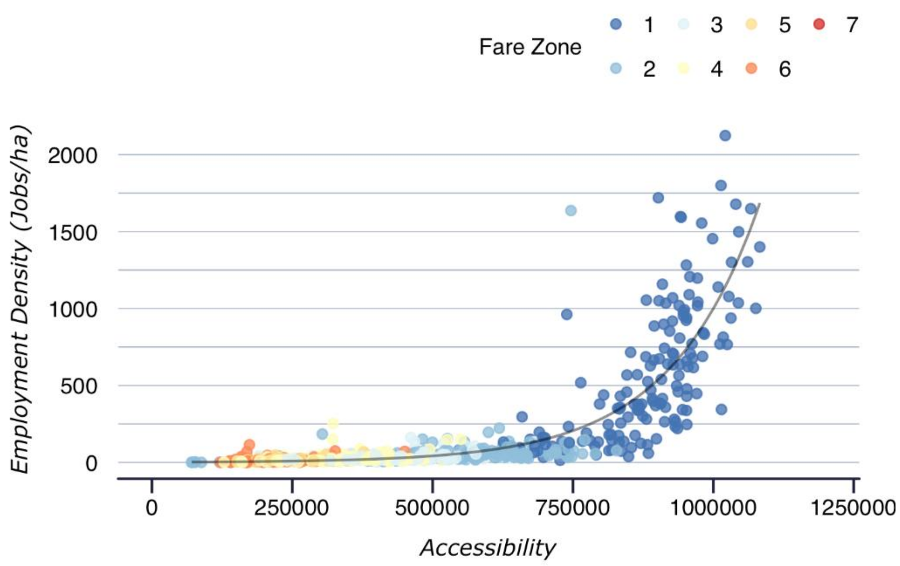


The relationship is exponential – the higher the level of accessibility a zone has, the greater the employment density response to further increases in accessibility. At accessibility scores below 600,000, almost no transport zones reach densities above 250 jobs/ha- Kingston Centre being the exception. These are also the majority of zones in the model, making up 74% of total zones. By contrast, the 10% most accessible zones in the model, with accessibility scores above 850,000, include just nine transport zones with employment densities below 250 jobs/ha.

It should be noted that while the relationship does appear to be exponential based on observed data, the data could follow an S-shaped curve, flattening out at very high accessibility scores as spatial constraints bite.

Figure 3 shows the accessibility density relationship for 2011, coloured by the transport fare zone it is in. The zones which have both high accessibility scores and high employment densities are almost exclusively in transport zone 1.

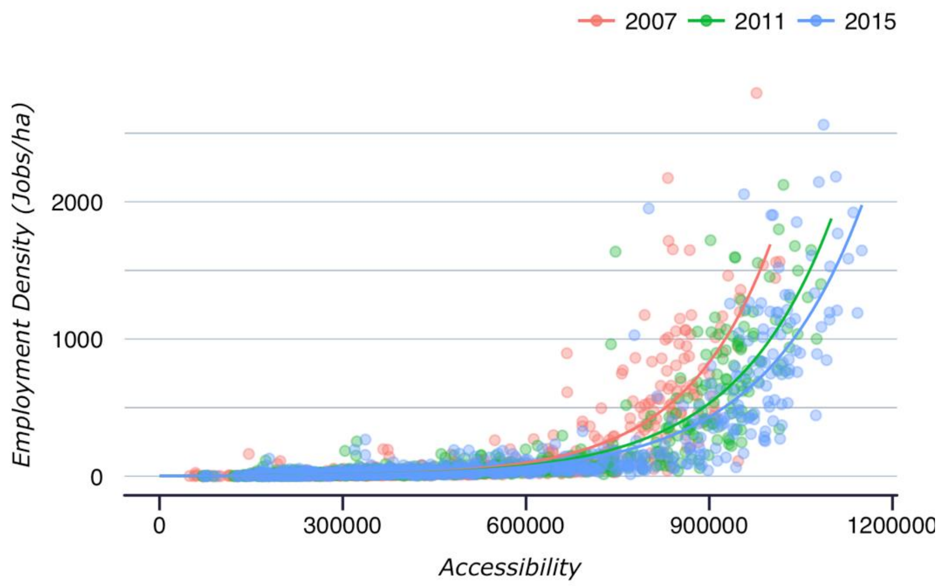
Figure 3: Accessibility: Density relationship for 2011, coloured by the London Fare Zone



4 The Time-Series Relationship

The time series relationship is difficult to pin down. Figure 4 shows how the fitted curve shifts outwards over time, suggesting that the relationship is changing. If population impacts dominate the Accessibility: Density relationship persistently, this shifting out of the curve may hold true. Without a static curve to work from, however, forecasting future impacts of accessibility on employment density becomes more complex.

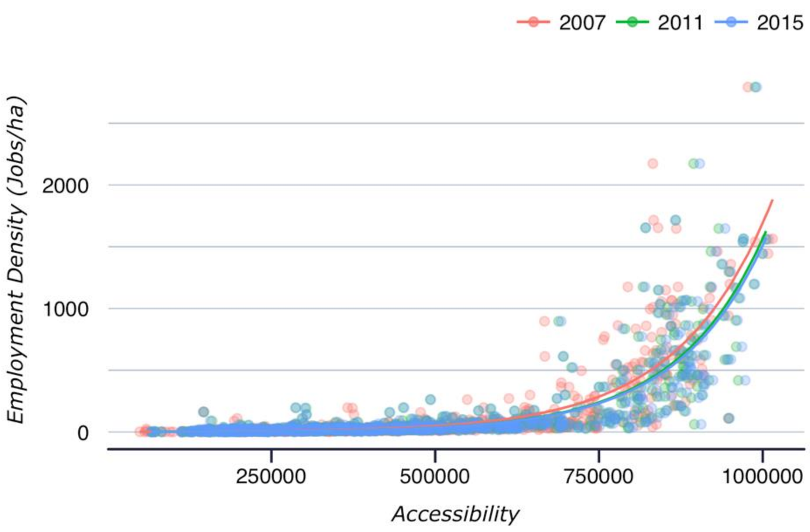
Figure 4: The Accessibility: Density relationship 2007-2015



Strong population and employment growth from 2007 to 2015 has increased both the Accessibility measure and Employment Density. Growth in both Population and Employment from 2007 to 2015 has occurred without any significant investments in transport. In the short term it is possible for London to grow without additions to accessibility, but in the long term transport capacity will need to keep up with demand.

Comparing Figures 4 and 5 demonstrates how population growth has driven the majority of changes in accessibility over the period, although the population growth itself may have been driven by the increase in jobs. There are strong elements of circularity in the process. Figure 5 shows that when holding population constant, the 2007-15 curves are almost identical.

Figure 5: The increase in accessibility when holding population fixed is minimal



One thing that is observed over time is the persistence of the relationship. Over the period 2007-2015, zones that are below the curve remain below the curve, and zones that are above the curve remain there. In fact, between 2007 and both 2011 and 2015, less than 12% of the zones in the model went from being below the curve to above, and vice-versa (shown in Figure 6).

Conclusions from this persistence effect are interesting. There are two possibilities:

1. Zones below the curve are below their 'potential' level of employment density because they are constrained by other (non-transport) factors. Adding more accessibility to such zones may not lead to employment density increases because there are other factors constraining the growth in jobs, for example planning policies, image, public realm, crime, pollution etc
2. The observed period (2007-2015) is short and development takes time. It also covers a period when little new transport infrastructure was introduced. The unmet 'potential' given the level of accessibility of a zone may be temporary: in time, development will occur and densities will rise. It takes at least 10-20 years for development to fully reflect a significant change in transport accessibility.

This leads to another difficulty in forecasting the impact of future accessibility improvements – should zones below the curve have lower expectations of an employment response to accessibility? Or should they expect to 'catch up' to their potential? And if so, how much of this potential is turned into development in any given time period? The answer will probably depend on why a zone is below the curve in the first place:

- Zones may be unattractive places for employment, for example areas close to waste disposal plants are unlikely to be attractive for development.
- Zones can have very restrictive planning policies and so cannot develop, despite their attractiveness to developers.

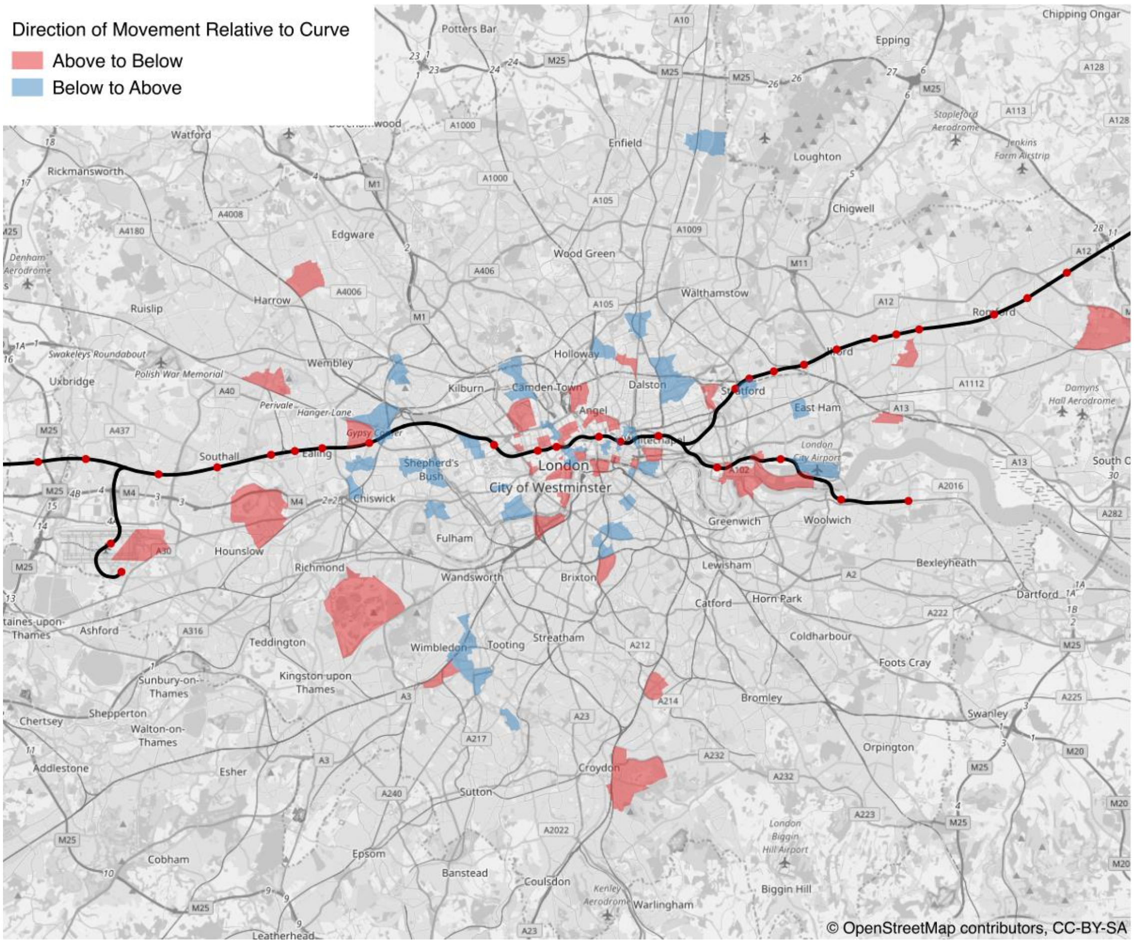
- Large, undeveloped, sites can take years of planning and large investments to bring about transformation. Such sites are risky to invest in and therefore less attractive to develop. An example is Kings Cross Railway Lands which has remained undeveloped partly due to its size, and therefore risk, to developers.

Due to these other constraints which may hold zones below the curve, Volterra analysed planning policy data to identify potential relationships between planning constraints and development densities. The process is shown in Appendix 4, but found no link between zones below the curve and planning polices in those zones.

Without being able to include constraints to growth into the model, and without a long enough time-series element to draw conclusions from, the results from forecasting must be treated with caution. This is especially true when considering development responses to the Jubilee Line Extension – job growth has been high in London Bridge and Canary Wharf, but very low in Waterloo, Canning Town, or West Ham.

A further observation is that jobs like to cluster. Places with already high employment densities are likely to continue to attract jobs, while it is hard to change low density areas into growing ones. This effect is not accounted for in the modelling, which accounts for access to population but not proximity to other jobs.

Figure 6: Zones moving from below to above the curve between 2007 and 2015



5 Creating a forecasting approach

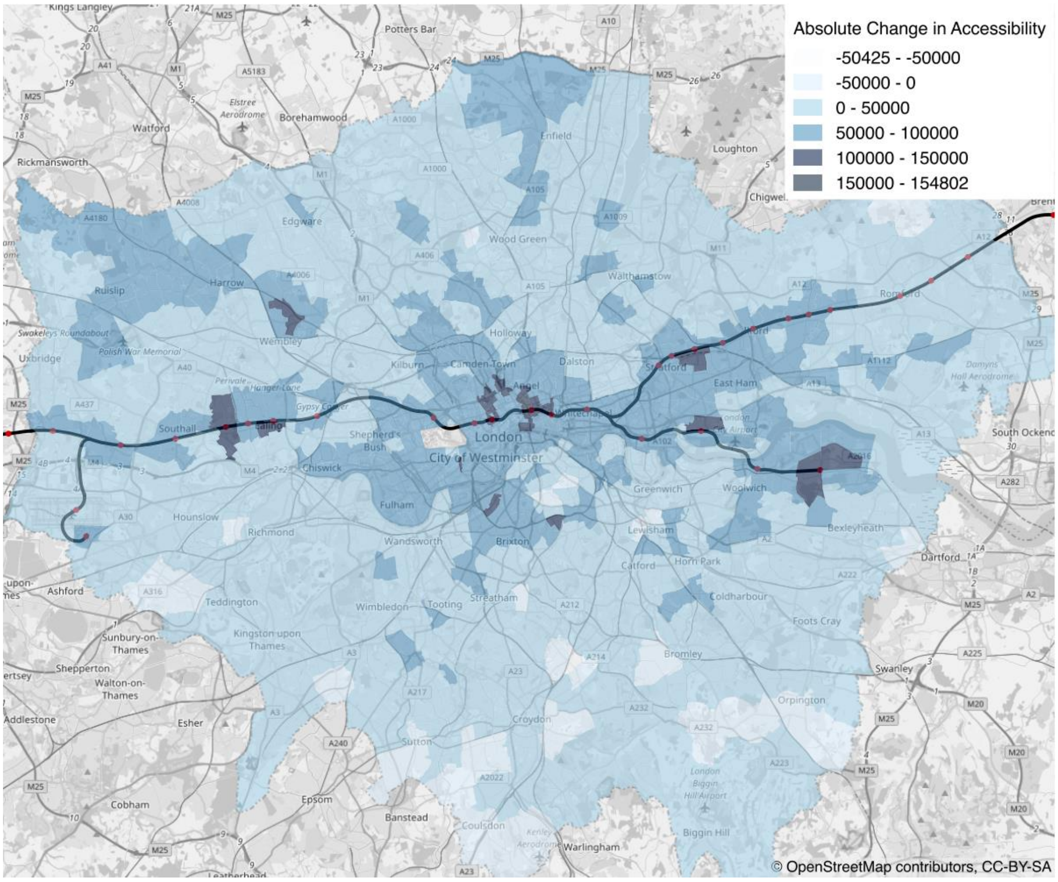
Using the Accessibility: Density relationship with a time-series aspect enables a prediction of the employment density response to transport changes. With this in mind, GT matrices for two 2041 scenarios are used to facilitate forecasts of future employment distributions throughout the London Boroughs. These scenarios are:

- 2041 Crossrail Scenario – Crossrail 1, HS2, and various line improvements (see Appendix 2)
- 2041 MTS Package – Crossrail One, Crossrail Two, and various underground and mainline upgrades (see Appendix 2)

As noted previously, increases in accessibility are influenced to a large extent by changes in population. To separate these impacts when calculating accessibility changes to 2041, population is held constant at 2011 levels and only the GT matrices are allowed to change. This gives us the pure transport impact on employment density.

Figure 7 shows the change in accessibility from the 2041 Crossrail scenario. The increase in accessibility generally follows the Crossrail alignment, with some outlying areas benefitting from new interconnectivity with the route.

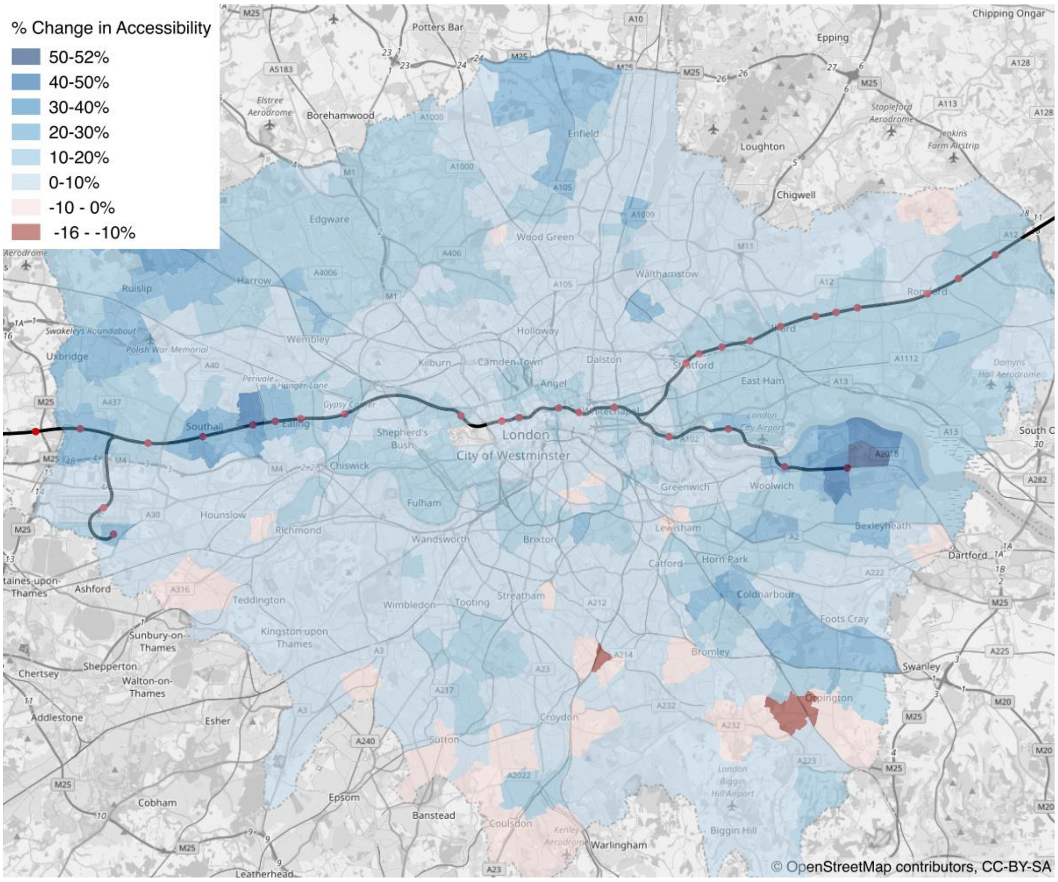
Figure 7: Increases in Accessibility from 2011 – 2041 under the 2041 Crossrail scenario



Based on the Accessibility: Density relationship, the areas with large increases in accessibility are likely to have more employment growth than those that have declining accessibility. To estimate the predicted impact that increases in accessibility from Crossrail will have on employment densities, the accessibility:density formula is applied to the 2041 accessibility scores. Applying the formula to the new accessibility scores allows for the future employment densities to be predicted, which are compared with the predictions from 2011, to give an estimated increase in density purely due to the accessibility improvement.

Without having the level of data required to correctly model the 'persistence effects', persistence is assumed to occur. Areas below the curve grew at an average CAGR of 3.2% between 2007 and 2015, while areas above grew at 4.3% per annum. Over the period between 2011 and 2041, those areas below the curve would be 40% below the level of those above. In the absence of local-level constraint data, a high level assumption is applied to zones below the curve, and employment impacts are reduced to 40% of the level of those above the curve.

Figure 8: Percentage Change in Accessibility from Crossrail under the 2041 Crossrail scenario



Due to the unconstrained nature of results, applying projected accessibility increases to the accessibility:density relationship likely result in excessively large job impacts. As noted in Section 4, this is due partly to the fact that constraints are not placed on zones and the assumed shifting of the relationship to 2041 is not accounted for.

In the absence of more concrete constraints, two approaches have been created. Firstly, an unconstrained growth approach was modelled, allowing zones to follow the exponential relationship. A Constrained growth model was then created, arbitrarily capping density increases in any given zone of 50%, with unconstrained results re-scaled on this basis.

Constrained Model

With no constraints placed on the model, the employment increase stemming from Crossrail become very large. Despite a 50% maximum density increase being an arbitrary cap, it is useful to see the scale of job impacts should constraints of this scale be imposed. Appendix 5 presents some of the difficulties in including more statistically driven constraints.

The results of this analysis are shown in Figures 9 and 10, which demonstrate that most of the impacts of the schemes are felt centrally. Table 3 shows the breakdowns of predicted employment impacts by Borough.

Figure 9: Absolute Change in Employment Density under the 2041 Crossrail scenario, constrained to 50% growth in employment density

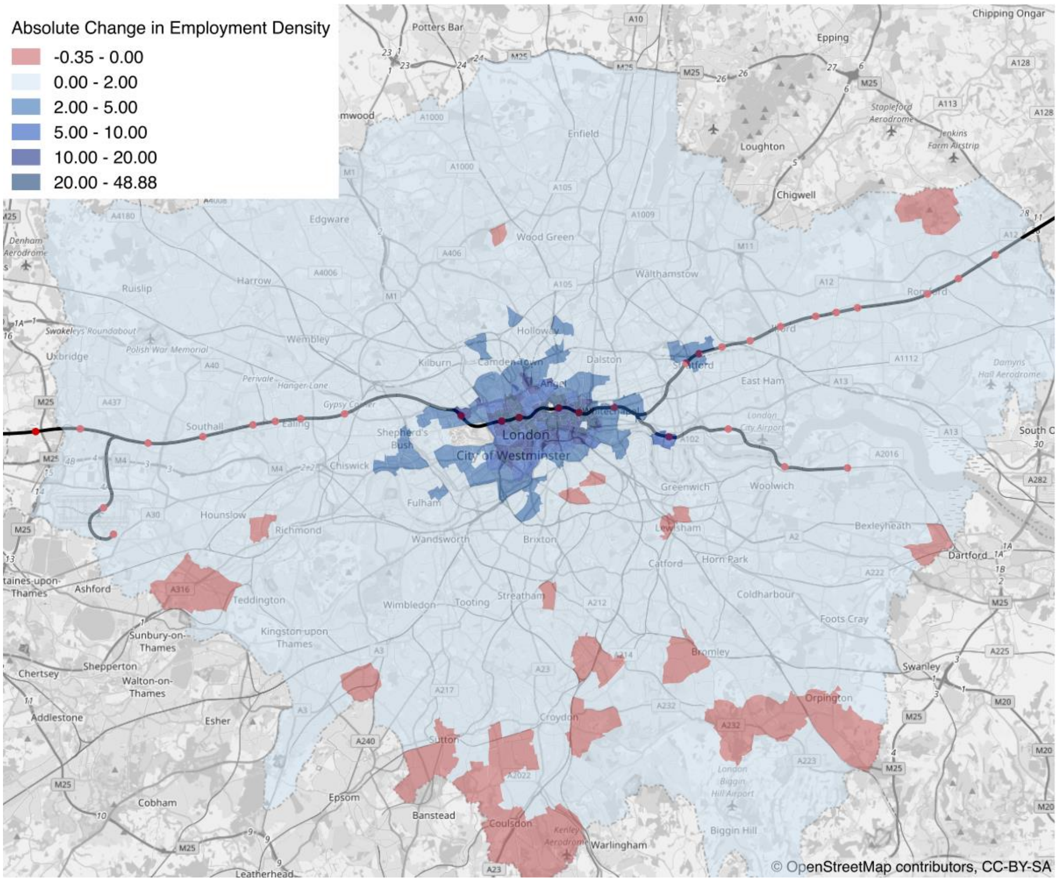
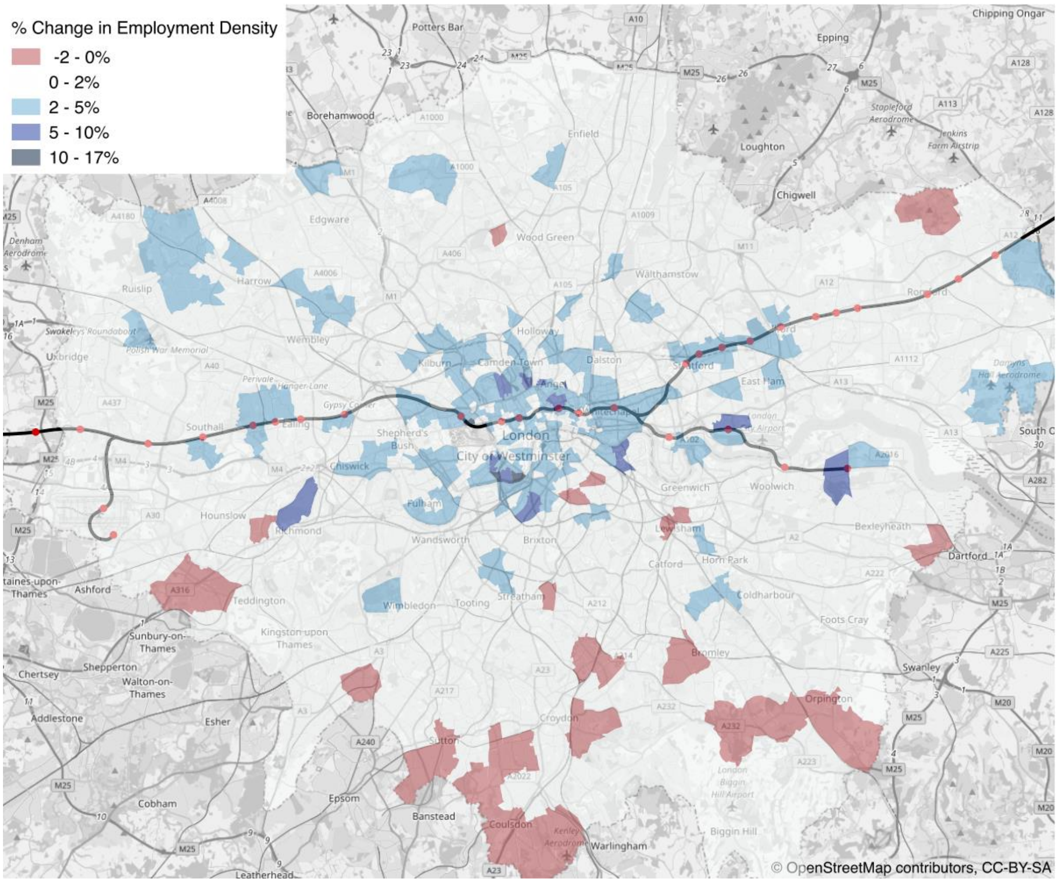


Table 1: Total Employment Impacts Expected under a constrained model (2011 – 2041)

Scenario	Central Sub-region	North Sub-region	East Sub-region	South Sub-region	West Sub-region	Total Increase
2041 Crossrail	41,700	2,400	12,400	3,300	7,000	66,800
2041 MTS Package	95,500	9,900	34,600	20,200	17,500	177,600

Figure 10: Percentage Change in Employment Density under the 2041 Crossrail scenario, constrained to 50% growth in Employment density



Unconstrained Model

The assumptions used in the constrained model are relaxed, removing the absolute and relative caps on how much density can increase in any given transport zone. The constrained model attempts to show realistically sized employment density increases given the likely time lags, and barriers to development presented in Section 4. An unconstrained model, by comparison, reveals the extent of development expected if no such constraints existed, and accessibility was the only factor under consideration.

The distribution of results under this scenario are identical, although the scale is far higher (see Table 4). The 2016 GLA employment projections over the period 2015-2041 give the same compound annual growth rate as the Crossrail only scenario predicted from the Accessibility:Density model. Employment is projected to increase from 5,538,000 in 2015 to 6,748,000 in 2041, a compound annual growth rate of 0.76% per anum.

Table 2: Total Employment Impacts Expected under an unconstrained model (2011-2041)

Scenario	Central Sub-region	North Sub-region	East Sub-region	South Sub-region	West Sub-region	Total Increase
2041 Crossrail	790,600	43,000	225,700	59,700	128,100	1,247,000
2041 MTS Package	2,085,200	180,400	629,400	366,300	317,600	3,579,000

Figure 11: Absolute Change in Employment Density under the 2041 Crossrail scenario, unconstrained

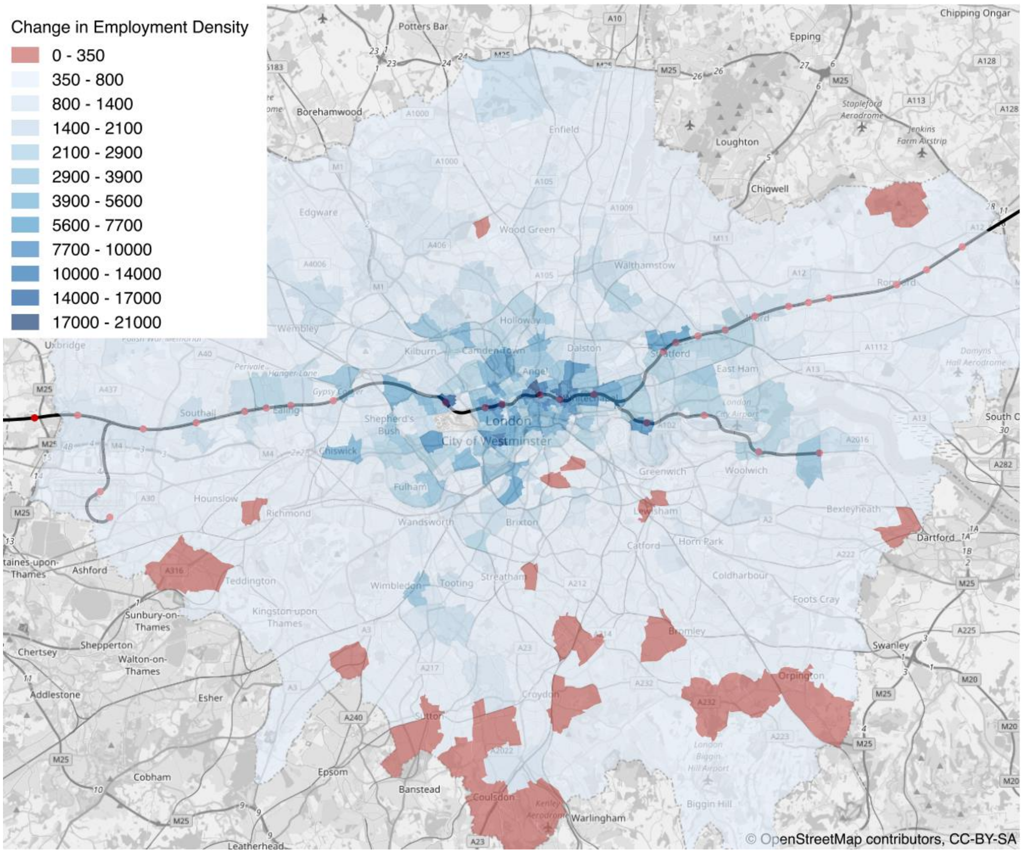
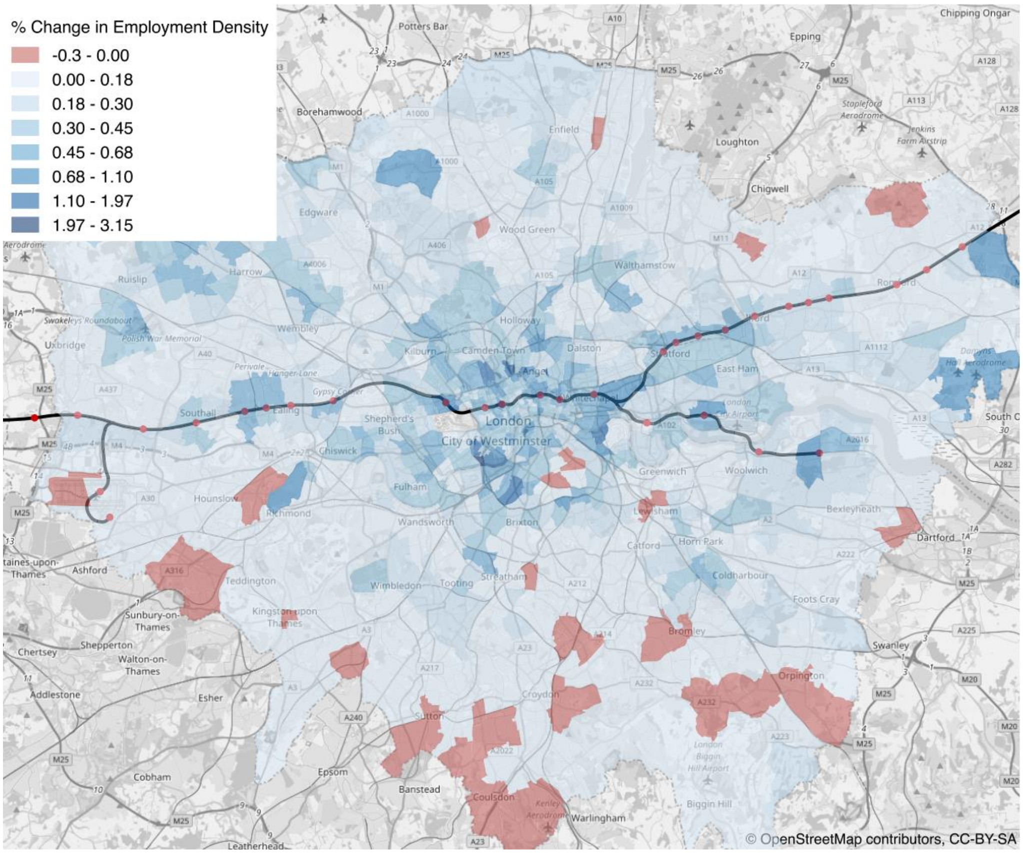


Figure 12: Percentage Change in Employment Density under the 2041 Crossrail scenario, unconstrained



6 Conclusions

The analysis into the relationship has shown that there is a strong statistical relationship between Accessibility and Density, in each of the years analysed. As has been demonstrated, accessibility is very important in determining employment density.

Growth in both population and employment has proved to be a very powerful way of increasing accessibility. Over the period analysed (2007-2015), population and employment growth has been responsible for almost all of the increases in employment density. High density employment zones seem to be self-sustaining, they grow faster than the lower employment zones, and this relationship has been shown to persist over time.

The accessibility increases under the two Crossrail Scenarios[2] lead to employment density uplifts which are broadly distributed across the central transport zones. This is to be expected due to the fact that these zones already have high levels of accessibility, and the accessibility:density relationship is one of increasing marginal returns to accessibility.

The lack of constraints imposed on the data means that the scale of results need to be treated with caution. In the constrained model, a 50% cap was imposed on density increases, and original results were rescaled to fit this assumption. The distribution of employment by Borough due to the scheme is likely to be a more robust measure of impacts to be expected from the schemes. The available evidence provides no indication of how and when transport constraints might bite. As discussed, such constraints might affect: the rate at which zones with the highest densities can grow; the extent to which growth of low employment density zones picks up; and the extent to which planning constraints hold back growth.

Removing constraints means that a number of zones quadruple in size over the period. Such results are indicators of the density that could be enabled by transport, in the absence of other constraints. Even without constraints placed on growth, over a 30 year period from 2011-2041, the increase in employment from 4,882,000 in 2011 to 6,129,000 under a 2041 Crossrail scenario represents an increase of just 0.76% per annum. This is identical to the last set of GLA projected forecasts from 2015 – 2041, which give a compound annual growth rate of 0.76% per annum also. If the entire MTS package of transport improvements is modelled, the growth rate increases to 1.8% per annum, although other constraints on growth are likely to bite.

[2] Crossrail One and Crossrail Two Scenarios contain a range of additional investments outlined in Appendix 2.

7 Appendix 1 – Tables of results

Table 3: Increases in Employment by Borough due to Increased Accessibility (with constraints)

Borough	**2011 Employment**	**Employment Increase Crossrail Only**	**% Increase**	**Employment Increase Crossrail Plus**	**% Increase**
City of Westminster	578,711	14,168	2.40%	30,539	5.3%
Camden	272,348	7,750	2.80%	18,620	6.8%
City of London	356,706	6,729	1.90%	8,958	2.5%
Islington	167,159	5,269	3.20%	14,378	8.6%
Tower Hamlets	234,726	3,784	1.60%	7,895	3.4%
Southwark	183,496	2,902	1.60%	9,587	5.2%
Lambeth	137,664	2,722	2.00%	8,095	5.9%
Newham	112,166	2,347	2.10%	5,564	5.0%
Kensington and Chelsea	116,546	2,156	1.80%	5,277	4.5%
Hammersmith and Fulham	124,530	1,966	1.60%	4,780	3.8%
Hackney	103,604	1,748	1.70%	6,033	5.8%
Ealing	132,461	1,488	1.10%	3,864	2.9%
Wandsworth	117,924	1,343	1.10%	7,672	6.5%
Brent	115,221	1,110	1.00%	2,649	2.3%
Barnet	129,112	1,044	0.80%	3,319	2.6%
Harrow	73,804	1,039	1.40%	1,660	2.2%
Hillingdon	164,963	999	0.60%	1,834	1.1%
Greenwich	86,199	984	1.10%	3,250	3.8%
Merton	75,223	795	1.10%	4,776	6.3%
Redbridge	78,894	721	0.90%	2,461	3.1%
Waltham Forest	79,221	692	0.90%	2,010	2.5%
Haringey	81,001	662	0.80%	3,669	4.5%
Enfield	105,493	659	0.60%	2,941	2.8%
Lewisham	78,895	649	0.80%	3,035	3.8%
Havering	84,726	532	0.60%	1,225	1.4%
Barking and Dagenham	58,444	522	0.90%	1,261	2.2%
Hounslow	128,880	446	0.30%	2,691	2.1%
Bexley	74,670	430	0.60%	1,896	2.5%
Bromley	111,405	377	0.30%	1,383	1.2%
Croydon	120,398	265	0.20%	1,694	1.4%
Richmond upon Thames	78,387	249	0.30%	1,512	1.9%
Sutton	72,286	135	0.20%	1,021	1.4%
Kingston upon Thames	72,450	123	0.20%	1,512	2.9%
TOTAL	**4,507,713**	**177,645**	**3.9%**	**66,805**	**1.5%**

Table 4: Increases in Employment by Borough due to increased Accessibility (without constraints)

Borough	2011 Employment	Employment Increase Crossrail Scenario	% Increase	Employment Increase MTS Package	% Increase
City of Westminster	578,711	260,210	45%	702,605	121%
City of London	356,706	151,880	43%	319,752	90%
Camden	272,348	141,068	52%	377,219	139%
Islington	167,159	95,920	57%	267,428	160%
Tower Hamlets	234,726	68,842	29%	143,480	61%
Southwark	183,496	52,790	29%	175,162	95%
Lambeth	137,664	49,534	36%	147,129	107%
Newham	112,166	42,703	38%	101,122	90%
Kensington and Chelsea	116,546	39,228	34%	95,898	82%
Hammersmith and Fulham	124,530	35,760	29%	86,866	70%
Hackney	103,604	31,801	31%	109,646	106%
Ealing	132,461	27,059	20%	70,233	53%
Wandsworth	117,924	24,422	21%	139,435	118%
Brent	115,221	20,173	18%	48,151	42%
Barnet	129,112	18,971	15%	60,317	47%
Harrow	73,804	18,902	26%	30,169	41%
Hillingdon	164,963	18,140	11%	33,332	20%
Greenwich	86,199	17,887	21%	59,067	69%
Merton	75,223	14,460	19%	86,805	115%
Redbridge	78,894	13,113	17%	44,731	57%
Waltham Forest	79,221	12,578	16%	36,525	46%
Haringey	81,001	12,021	15%	66,679	82%
Enfield	105,493	11,970	11%	53,442	51%
Lewisham	78,895	11,794	15%	55,159	70%
Havering	84,726	9,666	11%	22,259	26%
Barking and Dagenham	58,444	9,479	16%	22,923	39%
Hounslow	128,880	8,083	6%	48,898	38%
Bexley	74,670	7,804	10%	34,453	46%
Bromley	111,405	6,829	6%	25,137	23%
Croydon	120,398	4,785	4%	30,792	26%
Richmond upon Thames	78,387	4,502	6%	27,474	35%
Sutton	72,286	2,440	3%	18,553	26%
Kingston upon Thames	72,450	2,211	3%	38,097	53%
TOTAL	**4,507,713**	**1,247,024**	**28%**	**3,578,939**	**79%**

Table 5: Top 10 Employment growth zones under Crossrail Only Scenario, with constraints on growth set at 50%

Zone Name	2011 Employment	Employment Increase Crossrail Scenario	% Increase	Accessibility Increase	% Increase
Finsbury South	18,656	1,131	6.1%	154,802	18%
Westminster West	42,375	927	2.2%	94,626	10%
Barbican	23,157	923	4.0%	102,439	11%
Paddington Station North	22,557	852	3.8%	96,840	12%
Soho	17,843	742	4.2%	104,857	11%
Liverpool Street Station	40,855	695	1.7%	84,743	9%
Oxford Circus South	26,733	678	2.5%	93,555	9%
St Pauls	33,877	677	2.0%	78,813	8%
St Lukes West	12,354	672	5.4%	124,870	15%
Farringdon Station West	13,519	629	4.7%	153,783	17%

Table 6: Top 10 Employment growth zones under MTS Package Scenario, with constraints on growth set at 50%

Zone Name	2011 Employment	Employment Increase MTS Package Scenario	% Increase	Accessibility Increase	% Increase
Finsbury South	18,656	718	3.8%	247,808	29%
Paddington Station North	22,557	502	2.2%	180,124	22%
St Lukes West	12,354	468	3.8%	220,159	26%
Kings Cross and St Pancras	4,418	357	8.1%	210,060	24%
Holborn	19,611	334	1.7%	167,447	19%
Barbican	23,157	313	1.4%	171,946	18%
Wimbledon	13,815	308	2.2%	182,137	32%
Haggerston	17,539	301	1.7%	149,470	21%
South Lambeth East	4,903	300	6.1%	156,197	21%
Fitzroy Square	9,483	263	2.8%	195,333	21%

Table 7: Top 10 Employment growth zones under Crossrail Only Scenario, with no constraints on growth

Zone Name	2011 Employment	Employment Increase Crossrail Scenario	% Increase	Accessibility Increase	% Increase
Finsbury South	18,656	20,596	110%	154,802	18%
Westminster West	42,375	16,868	40%	94,626	10%
Barbican	23,157	16,796	73%	102,439	11%
Paddington Station North	22,557	15,505	69%	96,840	12%
Oxford Circus South	26,733	14,684	55%	93,555	9%
Liverpool Street Station South	24,225	13,892	57%	88,374	8%
Soho	17,843	13,511	76%	104,857	11%
Liverpool Street Station	40,855	12,642	31%	84,743	9%
St Pauls	33,877	12,322	36%	78,813	8%
St Lukes West	12,354	12,235	99%	124,870	15%

Table 8: Top 10 Employment growth zones under MTS Package Scenario, with no constraints on growth

Zone Name	2011 Employment	Employment Increase MTS Package Scenario	% Increase	Accessibility Increase	% Increase
Soho	17,843	49,642	278%	236,400	24%
Finsbury South	18,656	46,985	252%	247,808	29%
Oxford Circus South	26,733	41,186	154%	187,082	19%
Paddington Station North	22,557	38,960	173%	180,124	22%
Westminster West	42,375	37,460	88%	163,940	18%
Barbican	23,157	36,228	156%	171,946	18%
St Lukes West	12,354	30,747	249%	220,159	26%
Liverpool Street Station South	24,225	29,505	122%	150,528	14%
St Pauls	33,877	29,336	87%	147,328	15%
Holborn	19,611	28,873	147%	167,447	19%

8 Appendix 2 – Transport Packages

The transport interventions assumed to be delivered under the 'Crossrail One' package include:

Public Transport
HLOS 2 Rail Improvements
HS2
West Anglia Rail Devolution
Thameslink programme
Crossrail One
Great Western Electrification
DLR Improvements
Tramlink Improvements
Bus Improvements
Northern Line Extension
Tube Upgrades: Victoria, Jubilee, Northern

The transport interventions assumed to be delivered under the MTS transport package include:

Public Transport	Highway
Great Northern Frequency Upgrade (14tph to Moorgate)	Capacity reductions by street type:
Great Northern Metroisation	5% High road
Crossrail 1 frequency improvement (30tph)	25% City Hub
Great Eastern improvements (+3tph)	10% High Street, City Street, Town Square, City Place
Essex Thameside 12 car throughout peak	
Watford DC 4tph all day	
Croydon Tramlink Frequency uplift (7.5tph all routes)	
Bus priority in central London – 30% improvement in speed	
Low Emission bus zones (radial corridors) 20% on corridors	
Bus priority network plan – 20% speed improvement all links >25bph	
Brighton Mainline improvement	The Silvertown Tunnel
Southern Metroisation	
Southeastern Metroisation	
South West Trains Metroisation (Mainline Suburban and Windsor)	
West Anglia Mainline 4 tracking	
Beam Park Station	
Chiltern Line to OOC	
Brent Cross Station	
Heathrow Airport Western Access and Southern Access	
LO frequency increase ELL (24tph)	
LO frequency increase NLL (16tph)	
Clapham Junction – Willesden Junction (3tph)	
Gospel Oak – Barking 5tph peak service	
Bakerloo Line Upgrade (26tph)	
Central Line Upgrade (37tph)	

Waterloo and City Line upgrade (30tph)	
Piccadilly Line Upgrade (36tph)	
Northern Line Phase 3 upgrade – full separation (up to 36tph)	
DLR 30tph frequency increase	
Crossrail 1 Eastern Extension to Slade Green	None
HS2 phase 1 and associated NR changes	
Crossrail 2 and associated NR changes	
Hounslow – Old Oak – Brent Cross (4tph)	
Hounslow – Abbey Wood (6tph)	
GOB Barking Riverside Extension (6tph)	
GOB Abbey Wood Extension (6tph)	
Bromley North – Clapham Junction (4tph)	
Orbital rail/strategic interchanges multiple modes	
Bakerloo Line (33tph) post extension	
Bakerloo Line Southern Extension to Lewisham	
DLR Extension Gallions Reach to Abbey Wood	
DLR Extension Gallions Reach to Ilford	
Tram South Wimbledon to Sutton Extension(15tph)	
Beckenham Junction – Bromley North (7.5tph)	
Bus priority network plan – 20% speed improvement all links >25bph	

9 Appendix 3 – accessibility calculation

The Decay rate and Accessibility Measure

The accessibility measure is calculated using a gravity style model. The accessibility to population of each zone is found by measuring the Generalised time (GT) to a destination zone from all other origin zones. The resulting measure is weighted by the population in each of the origin zones, such that the zones with a higher number of residents are more important than zones with fewer residents.

Within the accessibility measure, we have also applied a “decay rate” which captures the relationship between the GT of a trip and the proportion of people who are willing to make that trip. A high decay rate shows that the proportion of trips from a given zone to various destinations falls rapidly as GT increases – People have a strong preference for shorter trips.

When applied to the model, this decay rate is used to give higher GTs an exponentially decreasing weight in the model, and lower GTs a far higher weighting. This attempts to capture people’s non-linear preferences for shorter GTs.

The worked example below uses example data from the first three zones (0,4 and 7) of the transport model for 2011. It shows the exact transformations that were undertaken with the full model matrices to derive the accessibility:density relationship.

Model Building Process

Step 1: Estimate a decay rate for the year we wish to model.

We apply equation 1 to observed data on origin/destination trips.

Equation 1: $P_{m,k} = \alpha \cdot \exp(\beta x)$

a) Take the demand and generalized time matrices for Public Transport

$$\begin{pmatrix} 19.1 & 31.5 & 0.8 \\ 7.2 & 94.2 & 1.0 \\ 1.8 & 6.9 & 2.1 \end{pmatrix} \qquad \begin{pmatrix} 4.28 & 7.91 & 24.5 \\ 7.88 & 8.59 & 22.70 \\ 23.43 & 22.22 & 6.34 \end{pmatrix}$$

matrix 1: public transport demand *matrix 2: Generalised Time*

b) Calculate the percentage of trips from an origin to every destination

$$\begin{pmatrix} 0.37 & 0.61 & 0.02 \\ 0.07 & 0.92 & 0.01 \\ 0.16 & 0.65 & 0.19 \end{pmatrix}$$

matrix 3: percentage demand from origin

c) Combine the data into single vectors for ease of analysis

- Transpose the matrices and stack the columns into a single column

$$\begin{pmatrix} 0.37 \\ 0.61 \\ 0.02 \\ 0.07 \\ 0.92 \\ 0.65 \\ 0.02 \\ 0.01 \\ 0.19 \end{pmatrix} \qquad \begin{pmatrix} 4.28 \\ 7.91 \\ 24.51 \\ 7.88 \\ 8.59 \\ 22.70 \\ 23.43 \\ 22.22 \\ 6.35 \end{pmatrix}$$

matrix 4: Stacked matrices of percentage demand (left) and GT (right)

d) Using the demand and GT vectors, fit the relationship in equation 1. We used the minpack.lm package in R which employs a Levenberg-Marquardt algorithm to solve for the best non-linear relationship given our functional form.

Figure 13: Decay rate estimation using the example data

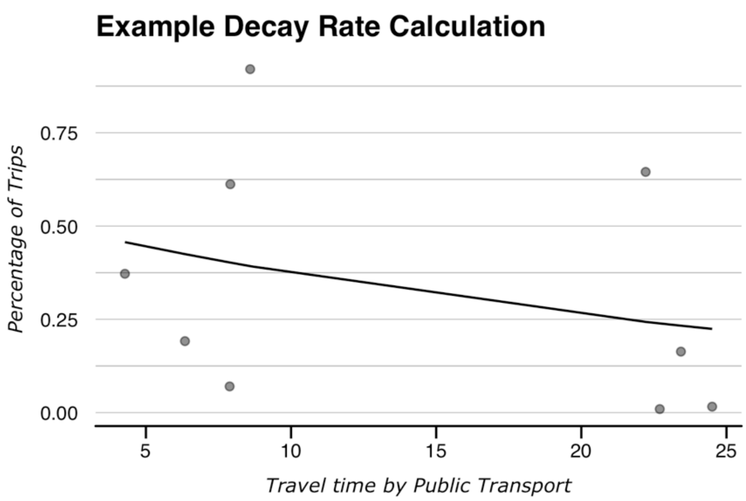


Figure 14: Summary Statistics from example decay rate estimation

```
Formula: y ~ a * exp(-b * x)

Parameters:
  Estimate Std. Error t value Pr(>|t|)
a  0.53098    0.30260   1.755    0.123
b  0.03516    0.04681   0.751    0.477

Residual standard error: 0.3289 on 7 degrees of freedom

Number of iterations to convergence: 7
Achieved convergence tolerance: 1.49e-08
```

- The estimate of b is then the decay rate used in the accessibility calculation.

Step 2: Calculate the accessibility score for each transport zone

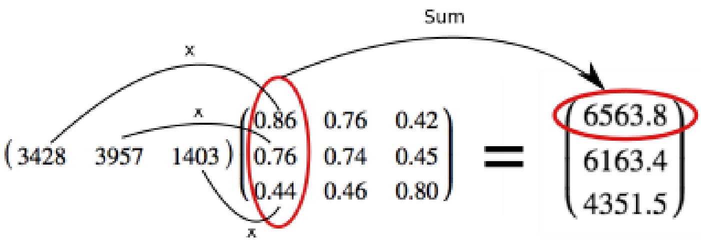
Equation 2: $Accessibility = \sum_{k=0}^{n} Population \cdot e^{-(Decay\ Rate)\cdot Generalised\ Time}$

a) Decay the GT matrix by the calculated decay rate (0.03516 following on from the previous example).

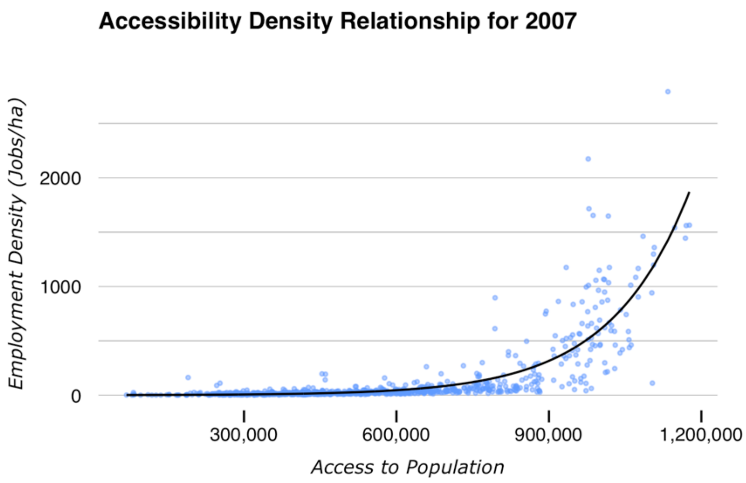
$$\begin{pmatrix} 4.28 & 7.91 & 24.5 \\ 7.88 & 8.59 & 22.70 \\ 23.43 & 22.22 & 6.34 \end{pmatrix} \xrightarrow[\text{e^-0.03516*x}]{} \begin{pmatrix} 0.86 & 0.76 & 0.42 \\ 0.76 & 0.74 & 0.45 \\ 0.44 & 0.46 & 0.80 \end{pmatrix}$$

a) Weigh GT by the population in each origin zone and sum for each destination.

- Using matrix multiplication, multiply *transpose*(population) * GT



10 Appendix 4 – Regression Results



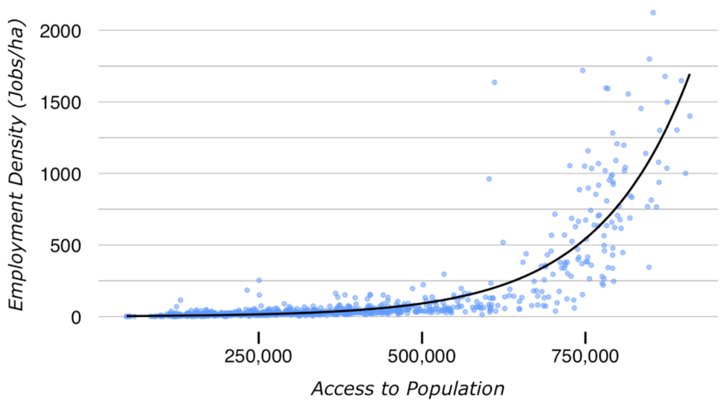

```
Formula: y ~ exp(a + b * x)

Parameters:
   Estimate Std. Error t value Pr(>|t|)
a 6.942e-01  1.729e-01   4.014 6.48e-05 ***
b 8.041e-06  2.311e-07  34.792  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 152 on 876 degrees of freedom

Number of iterations to convergence: 13
Achieved convergence tolerance: 1.49e-08
```

Accessibility Density Relationship for 2011



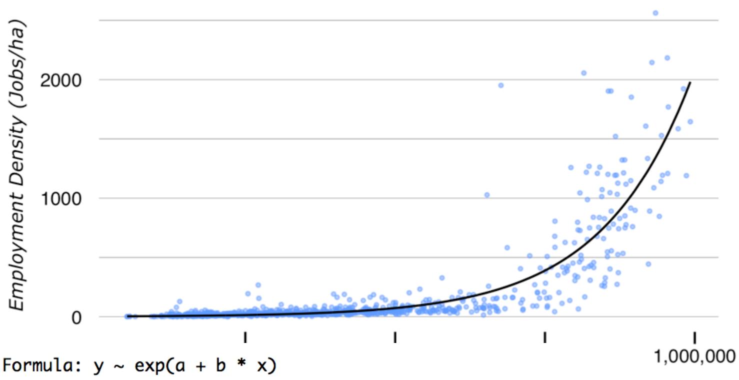

```
Formula: y ~ exp(a + b * x)

Parameters:
   Estimate Std. Error t value Pr(>|t|)
a 9.595e-01  1.697e-01   5.653 2.14e-08 ***
b 7.119e-06  2.098e-07  33.941  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 141.5 on 876 degrees of freedom

Number of iterations to convergence: 12
Achieved convergence tolerance: 1.49e-08
```

Accessibility Density Relationship for 2015




```
Formula: y ~ exp(a + b * x)

Parameters:
   Estimate Std. Error t value Pr(>|t|)
a 9.294e-01  1.782e-01   5.215  2.3e-07 ***
b 6.712e-06  2.007e-07  33.447  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 165.5 on 876 degrees of freedom

Number of iterations to convergence: 12
Achieved convergence tolerance: 1.49e-08
```

11 Appendix 5 – Planning Policy Constraint Analysis

In an attempt to explain some of the constraints on development in areas below the accessibility density curve, shape files of planning policy data were analysed. Areas below the curve are thought to have other constraints holding back development, other than transport. Looking at the geography of planning constraints, there appears to be no relationship between high level planning policies and the employment density of zones in the model. This appendix sets out the process used to investigate the relationship.

In the analysis we have considered a range of planning policies, in the form of shape files, which included:

- Article 4
- Safeguarded Wharves
- Conservation Areas
- Flood Risk
- Listed Buildings
- Localy significant industrial sites (LSIS)
- Strategic industrial locations (SIL)
- Viewing Corridors
- Sites of importance for nature conservation (SINC)

To get an idea of the impact of planning restrictions on the employment density, intersections of the planning shapefiles with transport zones were found. Where transport zones contain a planning restriction, we expected their employment densities to be below the accessibility:density curve. Table 9 shows that this expectation was not consistent with the data:

Table 9: Impact of Planning Policy on zones relative to the curve

Planning Policy	Zones Affected	Of which below curve
Article 4	293 (33%)	176 (60%)
Safeguarded Wharves	14 (2%)	6 (43%)
Conservation Areas	178 (20%)	81 (45%)
Flood Risk	611 (68%)	234 (38%)
Listed Buildings	792 (90%)*	388 (49%)
LSIS	235 (42%)	99 (27%)
SIL	148 (17%)	48 (32%)
Viewing Corridors	106 (12%)	66 (62%)
SINC	566 (64%)	260 (46%)

**listed buildings are better measured by how many buildings are within a zone. This analysis is also conducted.*

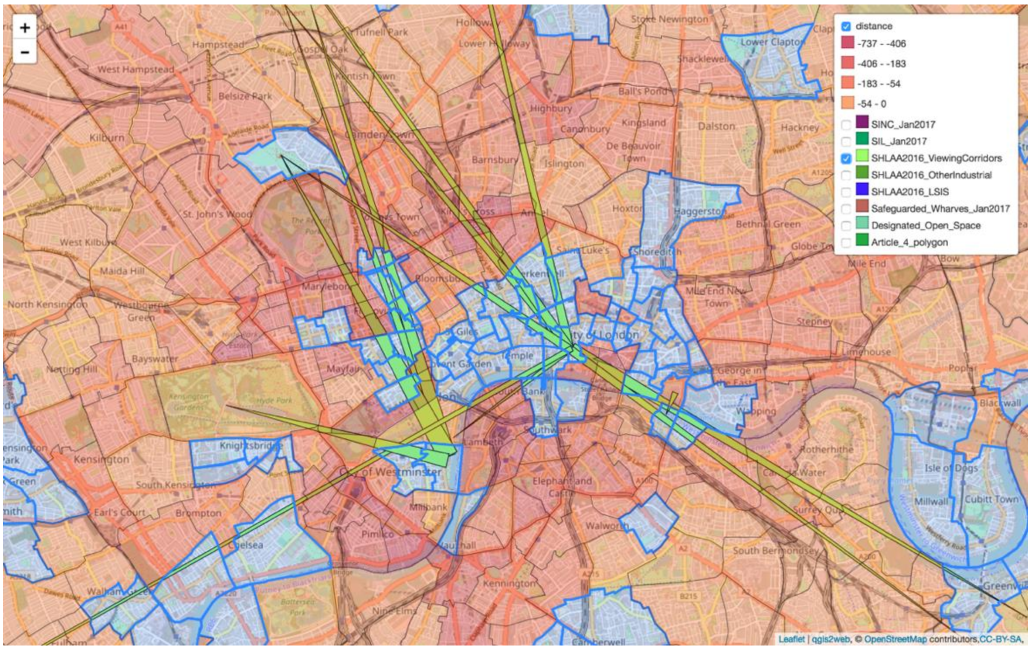
Of the planning constraints analysed, Table 9 shows that planning cosntrained zones are no more likely to be below the accessibility:density curve. In fact, only two of the planning policies have a majority of affected zones being below the curve.

In the case of listed buildings, the number of listed buildings in a zone is a better measure of the constraint than simply the existance of a listed building in a zone. Figure 15 plots the number of listed buildings against the distance from the curve. There is no obvious relationship between the number of listed buildings in a zone, and the distance from the curve.

Figure 15: The relationship between the number of listed buildings in a zone, and the distance from the accessibility:density curve

In the case of viewing corridors (vistas), they are locations which are in the sightlines of certain views around London. Any proposed development which would obsecure one of these views would be restricted. For this reason, Vistas have significant impact upon the height of buildings and therefore density.

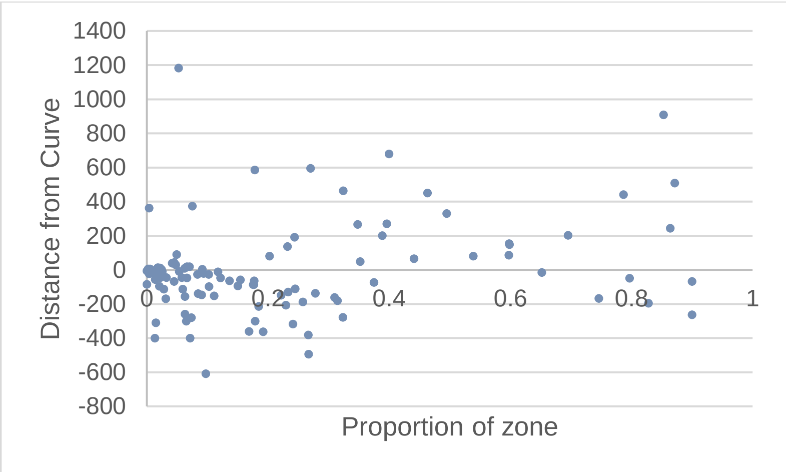
Mapping Viewing Corridors, we see that 12% of zones are affected by vistas to some degree. Of these zones 62% are below the curve, 39% are above. Out of all zones which are below the curve, 13% are affected by vistas whilst 11% of places above the curve are affected by vistas.



Despite vistas affecting a number of central zones which are below the curve, the vistas affect a number of centrally located zones which are far above the curve, obscuring any relationship. Zones such as St James's East are 90% covered by vistas and are below the curve, although Farringdon Station and Goodge Street West are also around 90% covered by vistas and are far above the curve.

Plotting the proportion of the zone covered by vistas against the distance from the curve, again shows no relationship between the two variables.

Figure 16: The relationship between the proportion of a zone under viewing corridor restrictions, and the distance from the accessibility:density curve



Looking at the shape file planning data does give an indication as to why some zones are below the curve. Zone above the curve often become very dense despite the planning restrictions. For this reason, constraints based on planning restrictions cannot easily be added to the accessibility:density model as the explanatory power has been found to be low overall.

Disclaimer