TRANSPORT CONNECTIVITY

Discussion paper

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INTRODUCTION

The National Infrastructure Commission published the first National Infrastructure Assessment[1] in July 2018. The Assessment looked at the United Kingdom's future economic infrastructure needs up to 2050, and set out a long term vision for infrastructure and a clear plan to achieve it.

The Assessment's evidence base involved an extensive programme of research and analysis. As part of this, the Commission asked Prospective Labs to construct a set of measures of transport connectivity. These measures assess the ease with which people can get around within, and between, different places in Great Britain. This analysis was used to inform the Commission's recommendations on urban transport, and key conclusions driven by the measures were included in the Assessment. The Commission also published a technical report, written by Prospective, setting out the detailed methodology for the connectivity measures.[2]

This discussion paper provides further clarity on the connectivity measures and how they can be used, as well as some initial insights into Great Britain's transport connectivity provided by the measures. The transport connectivity dataset has been published alongside this paper on the Commission's website.[3]

METHODOLOGY

The need for a transport connectivity metric

The Commission provides the government with impartial, expert advice on major long term infrastructure challenges. It has been tasked by the government with three high level objectives, to:

- Support sustainable economic growth across all regions of the UK
- Improve competitiveness
- Improve quality of life.

One of the key mechanisms through which infrastructure services can affect economic growth, competitiveness and quality of life is through improvements in transport networks.

Statistics and data of journey times to key services are published by the Department for Transport.[4] However, a comprehensive set of connectivity measures between and within places across the country is not currently publicly available. As such, the Commission considered this to be a key area to focus on developing new metrics.

The transport connectivity measures were developed as part of a wider infrastructure performance framework developed by the Commission with its objectives in mind. The Commission intends to use the measures in this framework, including connectivity, to quantitatively assess the current performance and shortcomings of infrastructure services across the country.[5] As only one aspect of the performance framework developed by the Commission, connectivity is not the only factor which affects the case for schemes. While it is an important dimension, it does not capture many of the economic, social and environmental costs and benefits which should also be considered as part of a cost benefit analysis. The National Infrastructure Assessment highlighted cost benefit analysis as an area which the Commission would continue to focus on as a separate piece of work, including developing alternative approaches where current methods perform less well.

The connectivity measures allow the Commission to compare connectivity across 1,000 places in the country. The comparison of connectivity during free flow and peak time[6] also gives an idea of congestion, again allowing for comparisons across the country. The Commission considers connectivity to be the effectiveness of the transport network at moving people around the country, be it within a place or between different places. The Commission asked Prospective Labs to develop three sets of measures of transport connectivity:

- **Urban connectivity** – or connectivity within places; by car, by public transport and across both modes
- **Inter-urban connectivity** – or connectivity between places; also by car, by public transport, and across both modes
- **International connectivity** – connectivity between cities and international gateways; Prospective developed an approach to measuring international connectivity, but it has not yet been estimated. This measure is not covered in this paper.

Built up areas

Prospective estimated connectivity for the 1,000 most populated places in Great Britain. Places were defined as ONS' built up areas.[7] Cities, following the Centre for Cities interpretation of primary urban areas,[8] were matched to built up areas where applicable. As some neighbouring cities are considered a single built up area by the ONS definition, this resulted in the grouping of certain cities into a single built up area – these are shown in Table 1. It should be noted that the 1,000 most populated built up areas includes places with a population of around 4,000 and above. This is below the urban classification used for the urban rural distinction in the 2011 census, which classifies an urban area as having a population above 10,000.[9] Any place with a population below 4,000, such as isolated communities and villages, remain excluded from the metric.

Table 1: Built up areas and corresponding cities[10]

Built up area	Cities included
West Yorkshire	Leeds, Bradford, Huddersfield, Wakefield
South Hampshire	Portsmouth, Southampton
Brighton and Hove	Brighton, Worthing

Urban connectivity

Urban connectivity (connectivity within places) is calculated using the average of travel times between each point in the place and its centre, weighted by demand (population or employment) in each point. The measure is calibrated so that places that are further away from the centre are given less weight, to reflect the impact of travel time/distance on willingness to travel.[11] Centres are defined as the output area[12] or areas with the highest employment density in each place.[13] In almost all cases the centre is defined as a single output areas, or as a set of adjacent output areas. In the case of London, two distinct centres are used: West End and City of London. Full details are set out in the Prospective Labs Transport Connectivity report published on the Commission's website.

The connectivity measures are normalised (ie divided) by secondary measures, calculated using the time it would take to travel in a straight line to the centre at a speed of 50 km/h, rather than using actual travel times.[14] The normalised connectivity measures represent the effectiveness of the network in providing access to the centre of a place, taking into account the physical proximity of people's locations. **Annex 1** provides further details on the formulas used by Prospective for the calculation.

As such, the measure captures both the speed of travel and the directness of the route, allowing for the likelihood people will want to make any particular journey. The measures are ratios of connectivity using observed travel times and connectivity using assumed travel times under straight line distances ('crow fly connectivity'), as shown below.

$$\text{connectivity} = \frac{\text{(observed travel time connectivity)}}{\text{(crow fly connectivity)}}$$

It is difficult to determine what 'good' connectivity looks like in absolute terms using these measures – although a higher ratio is better. A connectivity value of 1 means that the observed travel time connectivity is equal to the calculated crow fly connectivity, ie equivalent to being able to travel at 50km/h in a straight line on the weighted average of journeys. If the score of a place decreased from 1 to 0.5, it has halved its connectivity score; but that does not mean you can travel twice as fast.

The measure takes into account the fact that the importance of locations does not diminish linearly with increases in travel time: the difference between a journey time of 10 minutes and 20 minutes is not the same as a difference of, say, 2 hours 10 minutes and 2 hours 20 minutes. Weightings therefore decline in a non-linear way with journey time. However, capturing this means that the connectivity measure itself varies non-linearly with changes in travel times. It is relatively linear at speeds close to the 50km/h (crow fly) benchmark, but becomes more non-linear at higher or lower speeds.

Annex 2 provides simplified examples to demonstrate how the final connectivity value can be influenced by both a change in the observed travel time between points or a change in demand in specific points.

Inter-urban connectivity

Inter-urban connectivity (connectivity between places) is calculated in the same way as urban connectivity, except it measures distances/travel times between the centre of a place and the centre of other places.

Congestion

The main measures of connectivity reflect travel times during peak time, but measures of car connectivity at off peak were also calculated by Prospective. Comparing connectivity values during peak and off peak times can give a sense of congestion, assuming that there is free flowing traffic at off peak time. A significant difference implies that it takes much longer to get around during peak time than at off peak.

The Commission used the data provided by Prospective to construct an indicator of congestion, measured as the ratio of car connectivity at peak and off peak times.

$$\text{congestion} = \frac{\text{car connectivity at peak time}}{\text{car connectivity off peak}}$$

The lower the ratio, the more congestion in a place. A ratio of 1 would broadly indicate little or no congestion, as connectivity at peak and off peak is the same.

Although the congestion and connectivity measures are correlated, there is an important distinction. Congestion is often one aspect of poor connectivity, but other reasons exist – e.g. lower speed roads, lack of motorways/railways connecting two points, bus routes that take detours.

THE CONNECTIVITY DATASET

Prospective has produced connectivity metrics between and within places; by car, public transport and across modes; and using population and employment as demand weightings. There is data for each of the 1,000 built up areas considered for 28 variations of the metrics.[15] Details are provided in **Table 2**.

Table 2: Published connectivity measures constructed by Prospective Labs

	Type	Mode	Demand weighting	Time of day	Year
1	urban	car	population	peak	2011
2	urban	public transport	population	peak	2011
3	urban	combined	population	peak	2011
4	urban	car	employment	peak	2011
5	urban	public transport	employment	peak	2011
6	urban	combined	employment	peak	2011
7	urban	car	population	peak	2016
8	urban	public transport	population	peak	2016
9	urban	combined	population	peak	2016
10	urban	car	employment	peak	2016
11	urban	public transport	employment	peak	2016
12	urban	combined	employment	peak	2016
13	urban	car	population	off peak	2016
14	urban	car	employment	off peak	2016
15	inter-urban	car	population	peak	2011
16	inter-urban	public transport	population	peak	2011
17	inter-urban	combined	population	peak	2011
18	inter-urban	car	employment	peak	2011
19	inter-urban	public transport	employment	peak	2011
20	inter-urban	combined	employment	peak	2011
21	inter-urban	car	population	peak	2016
22	inter-urban	public transport	population	peak	2016
23	inter-urban	combined	population	peak	2016
24	inter-urban	car	employment	peak	2016
25	inter-urban	public transport	employment	peak	2016
26	inter-urban	combined	employment	peak	2016
27	inter-urban	car	population	off peak	2016
28	inter-urban	car	employment	off peak	2016

As mentioned, in addition to the measures shown above, the Commission calculated measures of congestion according to the method described and published this data. Details of the measures are shown in **Table 3**.

Table 3: Congestion measures calculated by the Commission using measures constructed by Prospective Labs

	Type	Mode	Demand weighting	Time of day	Year
29	urban	car	population	Peak/off peak ratio	2016
30	inter-urban	car	population	Peak/off peak ratio	2016

Given the nature of the measures, they are best used to compare connectivity or congestion between places, modes or points in time, rather than to make absolute judgments.

Direct comparisons between urban and inter-urban connectivity could be misleading. This is because the speed assumption (50km/h) used for the crow fly connectivity estimate is the same across both types of metric, therefore inter-urban connectivity will usually be better off as you can travel faster over longer distances.

The public transport connectivity includes bus, coach and rail. It also takes into account walking and waiting time based on service frequency for public transport. Public transport connectivity within smaller built up areas will often be by walking, so these values (when high) do not necessarily imply good internal public transport links.

The following section provides some examples of how this data can be used and interpreted.

FINDINGS

The Commission has undertaken some initial analysis to illustrate the types of insights that can be drawn using the connectivity measures. The measure of demand used to calculate connectivity was population in all the data shown in this section.

This analysis is just a start. New data has been made available on the Commission's website, and the Commission encourages interested stakeholders to explore the dataset further.

Urban connectivity

This section summarises findings on the ease with which people can get around by car and public transport within Great Britain's 1,000 most populated built up areas (urban connectivity).

Figure 1: Urban connectivity in Great Britain's 1,000 most populated built up areas, 2016

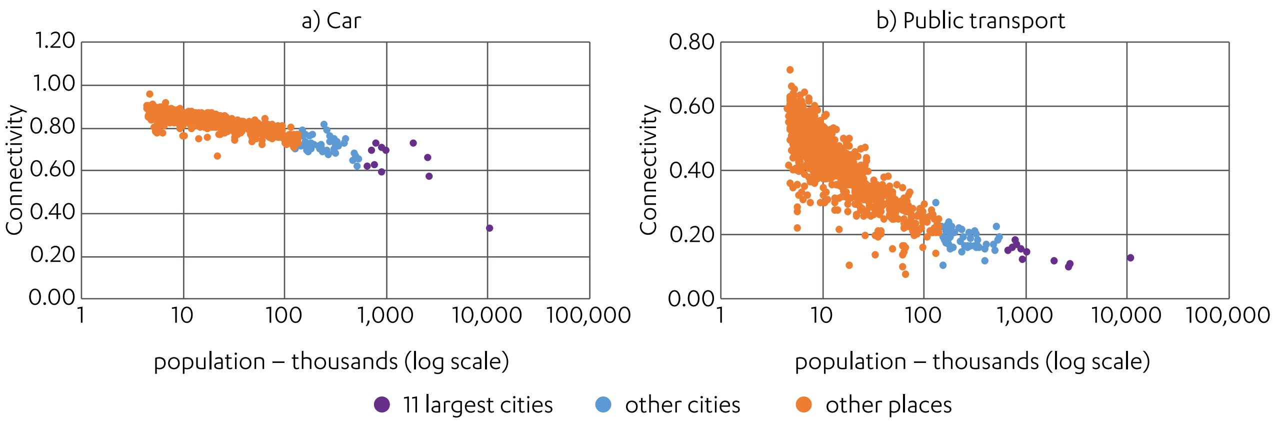


Figure 1 shows connectivity at peak time by car and public transport within Great Britain's 11 largest cities, all other cities[16], and other built up areas, plotted against population size. Using a log scale to show population allows for better visualization of the less populated built up areas, which would have been clustered together if a non-logged scale were used. Rather than a standard linear scale, each mark on the x axis has multiplied the previous mark by ten. By spreading out the clustered data, trends can be spotted more easily, allowing for more detailed analysis. **Table 4** shows the average urban connectivity by type of place.

Table 4: Average urban connectivity by type of place, 2016

	car			
	peak time	off peak	congestion (ratio peak to off peak)	public transport
London	0.33	1.35	0.24	0.13
10 largest cities (excluding London)	0.67	1.13	0.59	0.15
Other cities	0.72	0.99	0.73	0.19
Other places	0.84	0.92	0.94	0.43
All places	0.83	0.93	0.90	0.41

As **figure 1** and **table 4** indicate, urban connectivity by car is generally better than by public transport. This is true even in London, although the difference between car and public transport connectivity in London is significantly smaller than in other places.

Connectivity by both car and public transport tends to decrease with population size. This trend is most noticeable in car connectivity. More densely populated places are likely to have more traffic at peak time. This affects travel speeds into the centre and reduces connectivity. **Figure 2** shows the downwards trend in car connectivity as the population density increases, using density data from the 2011 census.[17] The ten lowest ranking built up areas for car connectivity support this narrative, as all are all major cities with a population greater than 460,000.

Figure 2: Car urban connectivity at peak in 2016 and population density in the most populated built up areas across England and Wales (census data excludes Scotland)

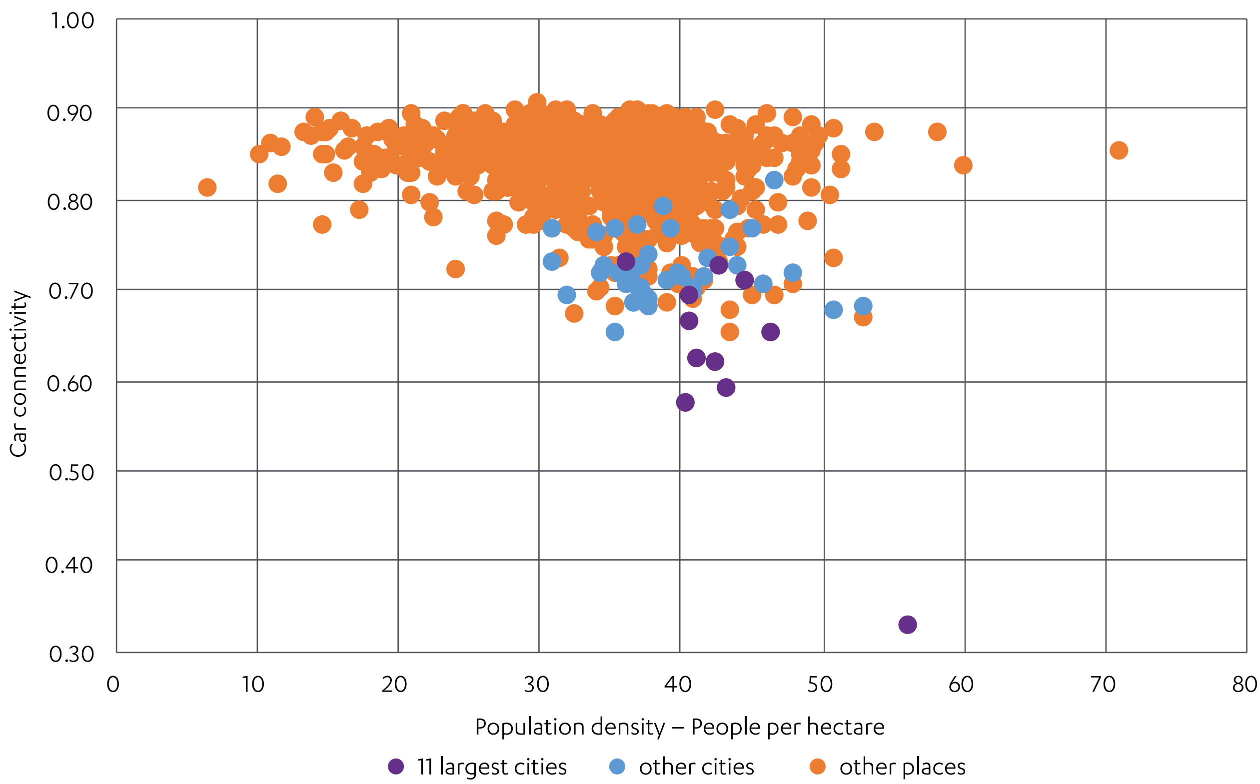


Figure 3: Urban car connectivity at off peak and congestion within Great Britain's 1,000 most populated built up areas, 2016

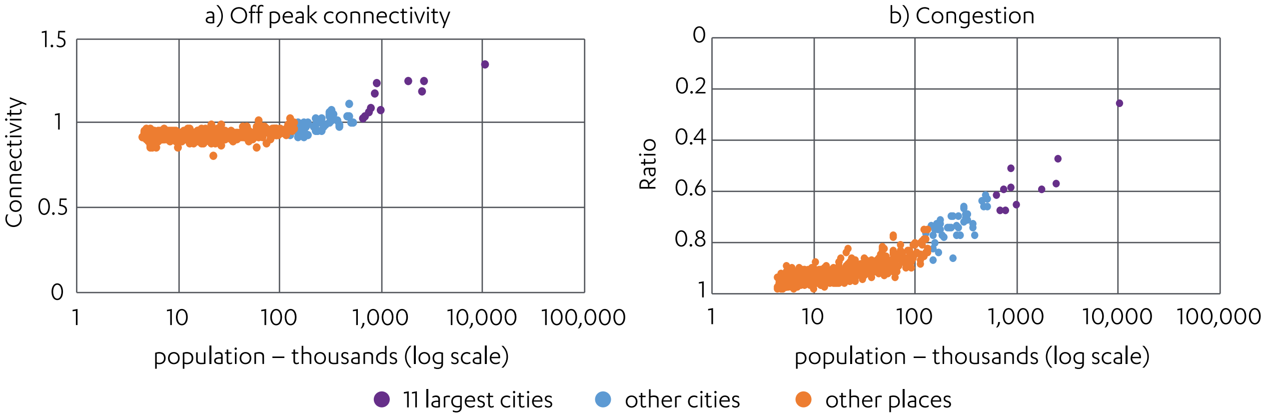


Figure 3a shows car connectivity at off peak – conversely to peak time connectivity, connectivity at off peak broadly increases with population size. The ratio of connectivity at peak time and connectivity at off peak gives a good sense of congestion, and as **figure 3b** suggests, the congestion metric also deteriorates with population size. Bigger places have faster, straighter roads, which means that off peak, they have higher connectivity. But the better roads are not sufficient to deal with the higher demands at peak time. So the congestion metric, especially in the biggest cities, is significantly worse than elsewhere.

Table 5: 15 most congested places according to the NIC congestion metric compared to the 15 local authorities with the longest average delay on ‘A’ roads, 2016 (includes England only, excluding London)[18]

Ranking	NIC congestion metric by built up area	Department for Transport average delay on locally managed ‘A’ roads by local authority (corresponding built up area in brackets)
1	Greater Manchester	Slough UA
2	Liverpool	Reading UA
3	West Midlands	Bristol, City of UA
4	South Hampshire	Manchester (Greater Manchester)
5	Nottingham	Tameside (Greater Manchester)
6	West Yorkshire	Brighton and Hove UA
7	Bristol	Liverpool
8	Brighton and Hove	Kingston upon Hull, City of UA
9	Leicester	Southampton UA (South Hampshire)
10	Bournemouth/Poole	Leicester UA
11	Southend-on-Sea	Wolverhampton (West Midlands)
12	Tyneside	Birmingham (West Midlands)
13	Sheffield	Nottingham UA
14	Kingston upon Hull	Portsmouth UA (South Hampshire)
15	Sunderland	Salford (Greater Manchester)

Table 5 compares the 15 most congested built up areas according to the calculated congestion metric with the Department for Transport’s average delay on locally managed ‘A’ roads by local authority in 2016. The average delay data is available at the local authority level so the full dataset cannot be directly matched to built up areas. London has been excluded from both rankings as the delay data is broken down to the borough level, which would make almost all of the 15 most congested places in Greater London. The table highlights that there are similarities between the areas which are found to suffer the worst delays on ‘A’ roads and are the most congested, with 13 out of the 15 local authorities with the worst average delay located within the top 14 most congested built up areas. Reading and Slough are the clear outliers in the table, which reflects the different approaches used to calculate the two metrics. Although, both Reading and Slough also rank within the top 50 most congested built up areas.

As **figure 1b** shows, urban public transport connectivity also tends to decrease with population size. However, London has comparable public transport connectivity to other large cities despite having a significantly larger population, although it remains one of the ten lowest ranking built up areas for both car and public transport connectivity. West Yorkshire (Leeds/Bradford) is in the bottom ten for public transport connectivity, but not for car connectivity. A potential explanation for this is that West Yorkshire is one of the few large metropolitan areas which does not have an established mass transit system.

Two factors are likely contributing to low public transport connectivity in cities relative to smaller places:

- The public transport connectivity measure includes waiting times when changing between transport modes – in larger cities, many trips to the city centre will involve multiple changes, which increases travel time and consequently reduces connectivity;
- Many places are largely served by buses, and even if services are frequent, they will be affected by congestion, unless special provision is made e.g. intermittent bus lanes. Bristol is a good example of this.

There is a mixture of large and small places in the ten lowest ranking areas for public transport connectivity. This suggests a combination of poor connectivity due to congested public transport services and roads in larger cities, and due to poor or limited public transport provision in some smaller places.

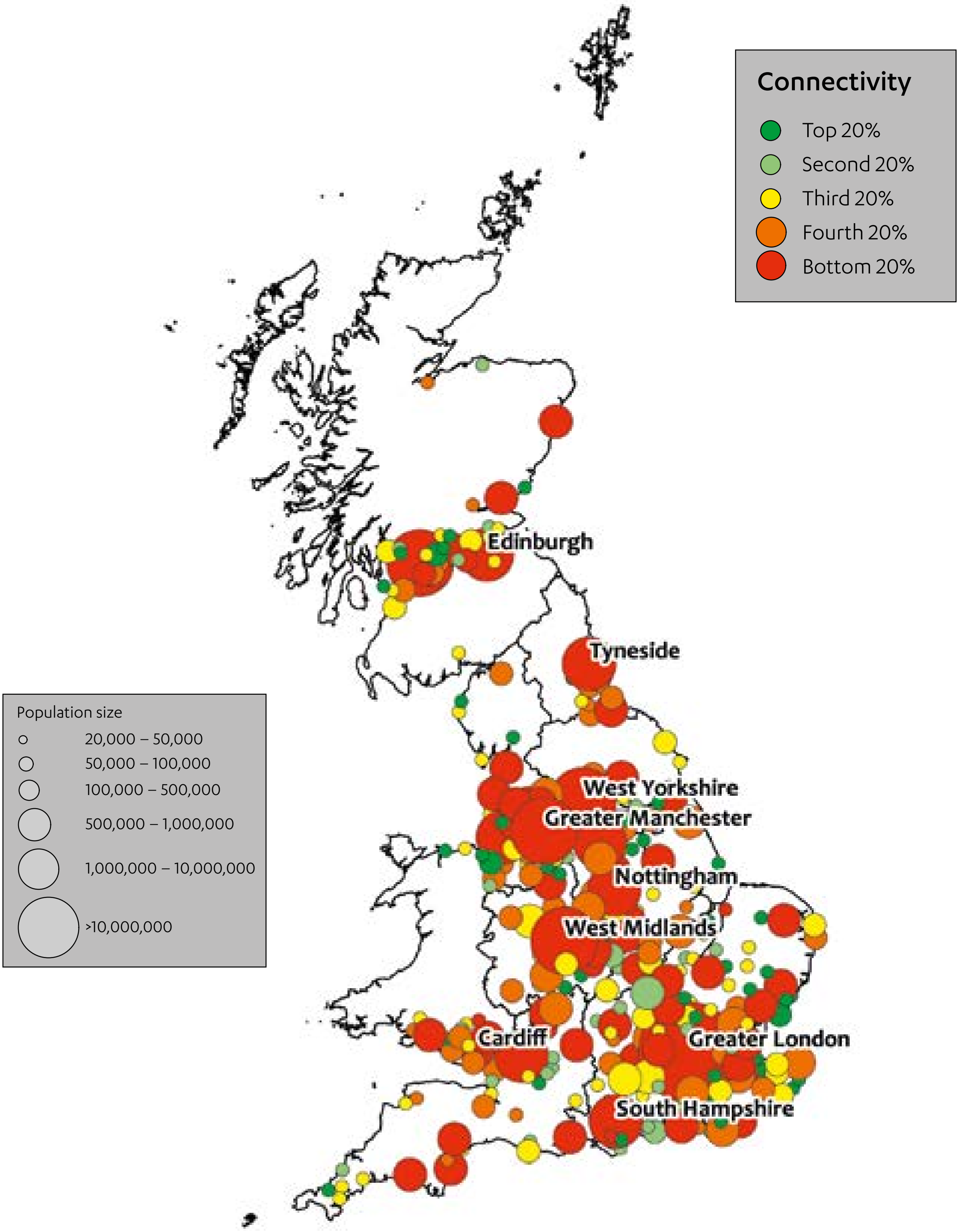
Figure 4a maps urban connectivity by car and **figure 4b** the congestion metric for Britain's towns and cities.[19] Although no regional trends are immediately apparent, larger places (represented by the size of the bubble) generally have worse car connectivity and are more congested, as **figure 2** and **figure 3** suggest. **Table 6** highlights London and the North West as two regions with relatively poor car connectivity. Looking at the 50 largest cities, all except Milton Keynes are in the bottom 20%. This could be because Milton Keynes was planned and built as a new town to minimise congestion as far as possible. As the city was designed to grow rapidly, its novelty was to avoid big urban traffic flows by spreading traffic flow and traffic density.

Comparing **figure 4a** and **4b** suggests that the trends observed in the congestion metric are very similar to the trends observed in urban connectivity. This would indicate that congestion is a key driver of poor urban car connectivity. There are a number of exceptions across the country. This would suggest that the relatively low connectivity in these places is driven by reasons other than congestion.

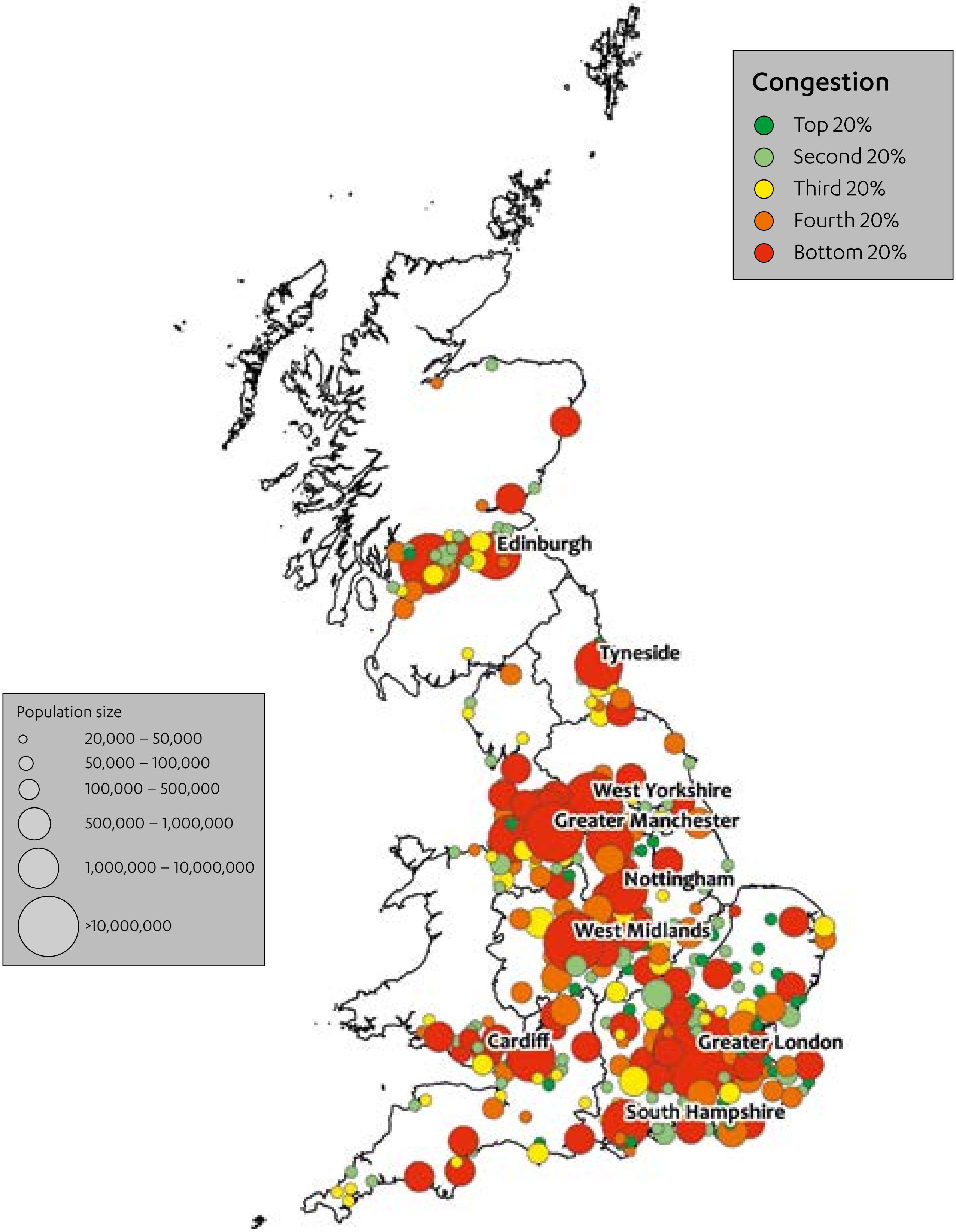
Figure 4c shows urban public transport connectivity. The pattern is similar to that observed for urban car connectivity. There are again a few exceptions, for example Milton Keynes, which has car connectivity towards the middle of the range, has relatively bad public transport connectivity. Conversely, Exeter has relatively bad car connectivity, and public transport connectivity in the middle of the range. **Table 6** shows London, the North West and the West Midlands to have relatively poor public transport connectivity.

Figure 4: Maps showing urban connectivity, 2016

a) Car connectivity (peak time)



b) Congestion



c) Public transport connectivity (peak time)

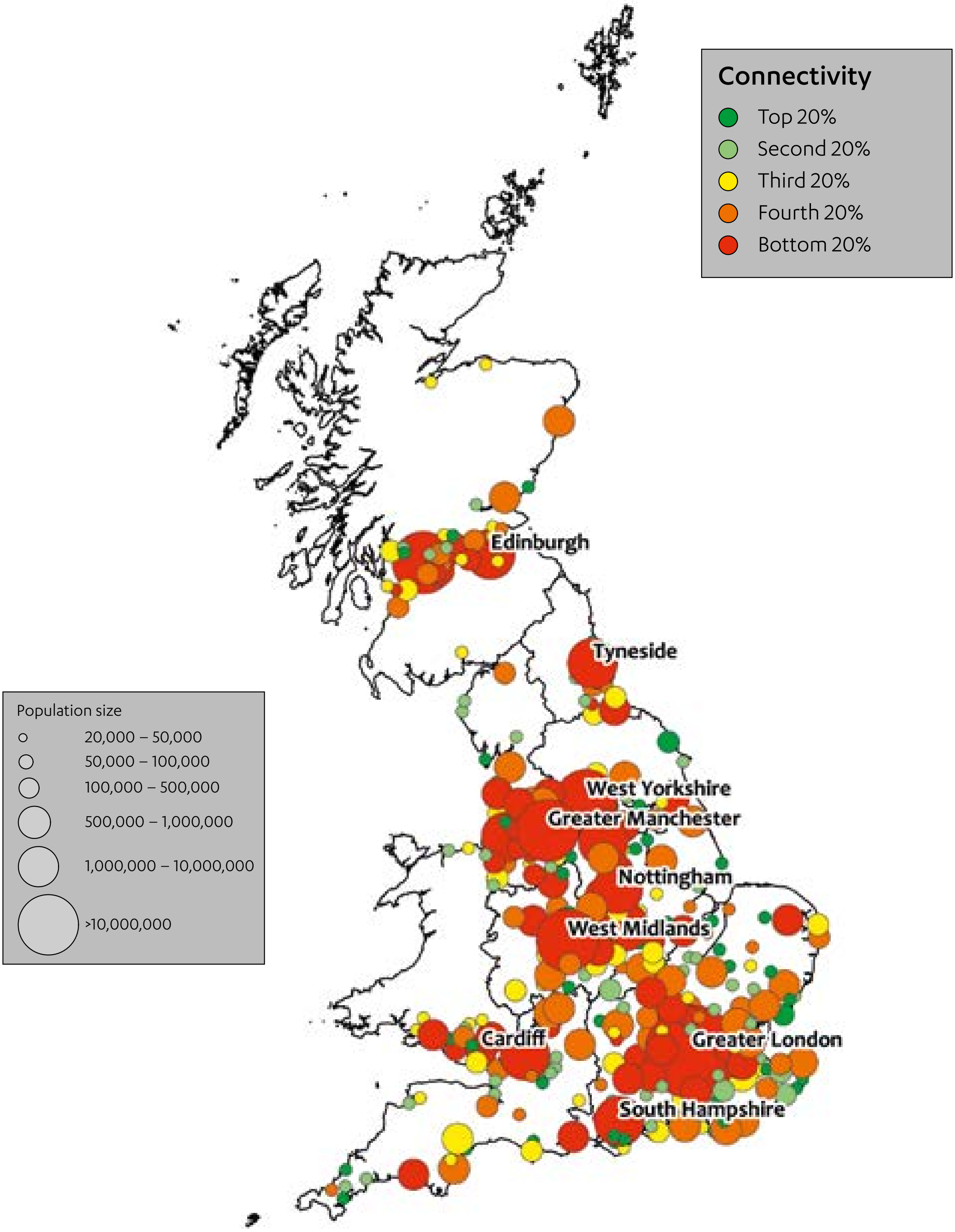


Table 6: Average urban connectivity by region, 2016 (weighted by population in each built up area)[20]

Region	Car	Public transport
East of England	0.78	0.29
South East	0.77	0.26
North East	0.76	0.23
Wales	0.76	0.26
Scotland	0.75	0.26
East Midlands	0.74	0.26
South West	0.74	0.26
Yorkshire and The Humber	0.74	0.21
West Midlands	0.71	0.18
North West	0.67	0.19
All built up areas	0.66	0.22
London	0.33	0.13

Inter-urban connectivity

This section summarises findings on the ease with which people can get around by car and public transport between Great Britain's 1,000 most populated built up areas (inter-urban connectivity).

Figure 5 shows connectivity at peak time by car and public transport between Great Britain's 11 biggest cities, all other cities, and other places, plotted against population size. **Table 7** shows the average inter-urban connectivity, by type of place.

Figure 5: Inter-urban connectivity for Great Britain's 1,000 most populated built up areas, 2016

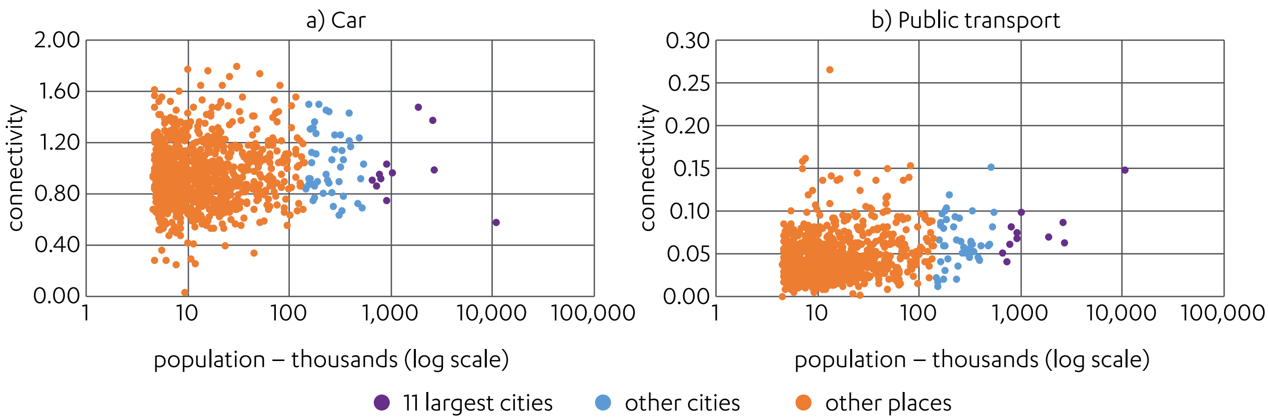


Table 7: Average inter-urban connectivity by type of place, 2016

	car			public transport
	peak time	off peak	congestion (ratio peak to off peak)	
London	0.58	4.67	0.12	0.15
10 largest cities (excluding London)	1.02	3.09	0.34	0.07
Other cities	1.03	3.09	0.34	0.07
Other places	0.94	2.52	0.39	0.04
All places	0.95	2.55	0.38	0.05

As **figure 5** and **table 7** indicate, inter-urban connectivity by car is substantially better than by public transport. The difference is much greater than that of urban connectivity. Off peak connectivity is shown to be significantly better for larger cities than it is for other towns and smaller built up areas. A likely explanation for this is that bigger places have faster, straighter roads between them, but they also have more cars.

There is not as clear a trend between population size and inter-urban connectivity by car. Connectivity by car for the smallest of the 10 most populated cities is on average lower than in other cities. Whereas connectivity by car in some of the larger cities (West Midlands and West Yorkshire) is significantly better than average. Looking at the ten highest ranking built up areas for car connectivity, a range of regions and population sizes are found.

There is a slight upward trend in public transport connectivity as population size increases. Larger places tend to be better served by rail which reduces travel times and improves their connectivity, and this is reflected in the data. London has one of the highest inter-urban public transport connectivity values of all the 1,000 places looked at. Ashford and Brighton in the South East are also ranked within the highest ten built up areas. This can similarly be explained by direct and regular trains running into central London. A clear exception to the trend observed with population is Barrow-in-Furness in the North West, with a relatively large population of 45,000. This town has a very poor car connectivity, with the likely cause for this its constrained geographical location at the tip of the Furness peninsula.

Berwick-upon-Tweed in the North East is the clear high outlier for public transport connectivity, with the result 0.27 compared to the next highest result at 0.16. One likely explanation for this is Berwick-Upon-Tweed's inclusion as one of few stops between London Kings Cross and Edinburgh on the East Coast Main Line. The journey along the entire line takes just over four hours and multiple trains pass through Berwick in both directions every hour. Berwick is also a regular cross country stop from Scotland to Cornwall, stopping at major cities such as Leeds and Birmingham on the way.[21]

Most of the ten highest ranking built up areas for public transport connectivity are located in Scotland. Possible explanations for some of these outliers could be that the majority of the population live in and around Glasgow and Edinburgh which are fairly well connected cities, and the connectivity metrics are weighted by population. There are also well established train routes across Scotland which link some clusters of smaller built up areas to Glasgow and Edinburgh.[22]

When looking at the ten lowest ranking built up areas, for both car and public transport connectivity the majority are located in the South West and Scotland. Potential explanations for this are the constraining geography of these areas, such as mountains and lakes in Scotland, and that both are further away from the rest of the country than other regions, i.e. the South West is situated on a peninsula. Although the metrics have been normalised to control for crow fly distance, these constraints and limited motorway access can mean that the routes taken are likely to vary significantly from the crow fly direction and assumed speed.

Figure 6: Inter-urban car connectivity at off peak and congestion for Great Britain's 1,000 most populated built up areas, 2016

Figure 6a shows a similar pattern in car inter-urban connectivity at off peak times as that seen at peak time. The slight upwards slope supports the argument that bigger places are likely to have the fastest, straightest connections. **6b** shows that there is no marked trend in the congestion metric, although inter urban congestion is significantly worse for London than anywhere else (**Table 7**). As this measure reflects connectivity between the centres of different places, congestion to get into London's centre is likely to be contributing to its high inter-urban congestion.

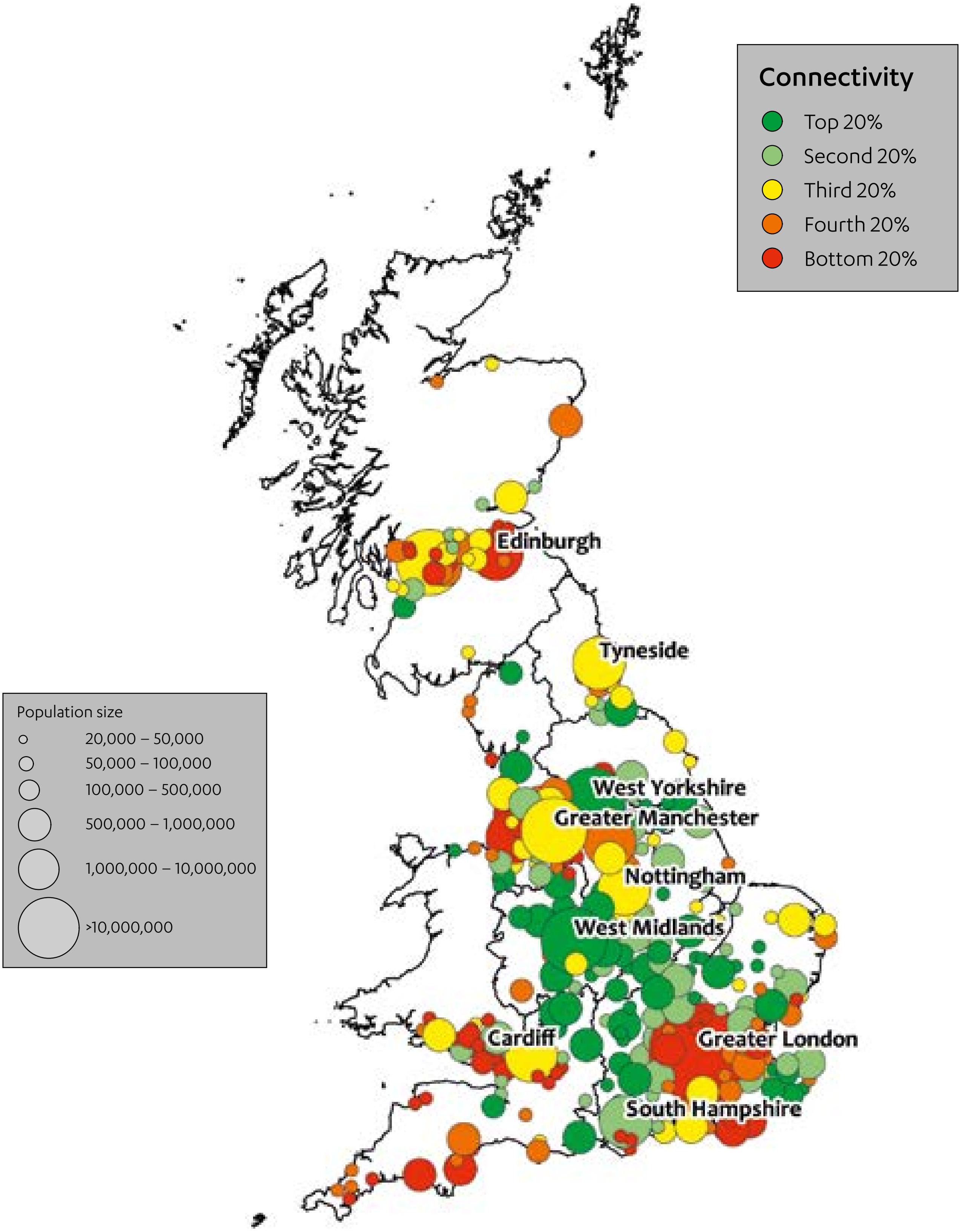
Figure 7a maps inter-urban connectivity by car and **figure 7b** congestion between Britain's towns and cities.[23] There are a number of regional patterns which can be observed; for the congestion metric there appears to be a concentration of more congested inter-urban routes in the South East, East Midlands and North West. **Table 8** highlights that when the regional average is calculated and weighted by population, most regions have fairly similar car connectivity. London, Scotland and Wales are highlighted as relatively worse than other regions.

Comparing **figure 7a** and **7b** suggests that the trends observed in the congestion metric are not correlated with the trends observed in inter-urban car connectivity. The key difference to highlight is that a high number of the larger cities are shown to have good inter-urban car connectivity, but with relatively high congestion. This suggests that the congestion metric is not the main factor driving inter-urban car connectivity. This can be seen across the North East around Newcastle and the Midlands around Nottingham and Coventry. Although London is ranked within the bottom 10 for inter-urban car connectivity and has relatively high congestion, the surrounding places are shown to have significantly better car connectivity yet also relatively high congestion. There are some exceptions to this pattern, for example the South West is shown to have little congestion, but poor inter urban connectivity.

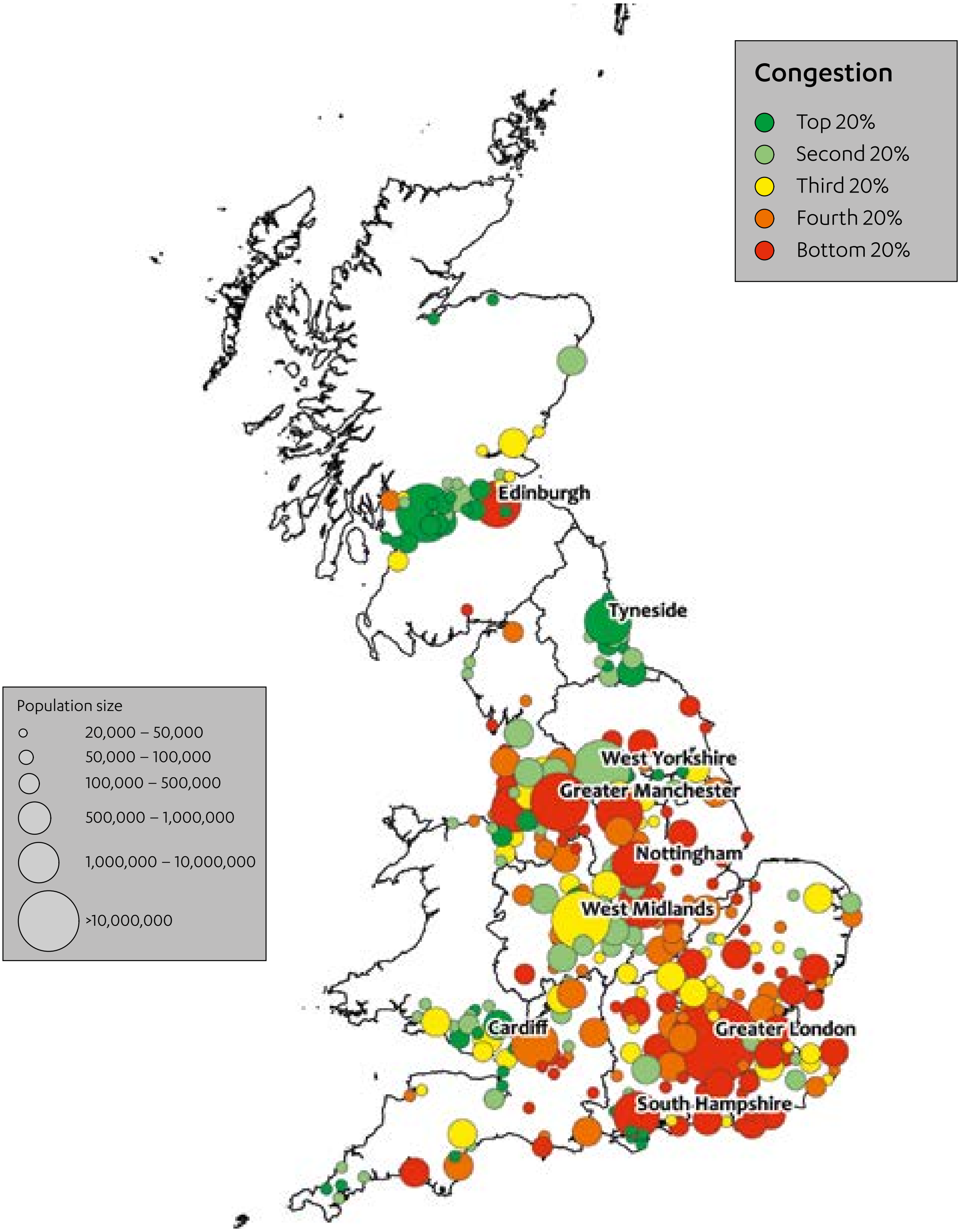
Figure 7c shows inter-urban public transport connectivity. Unlike urban connectivity which shows broadly similar trends across car and public transport connectivity, very different patterns can be observed here. Although no regional trends are immediately apparent, larger places (represented by the size of the bubble) generally have better connectivity by public transport, as discussed previously. The region around London is shown to be significantly better connected by public transport than the rest of Great Britain in **table 8**. There are exceptions to the trend around larger cities, such as Sheffield which has the 11th largest population of all cities, but ranks towards the middle of the range for inter-urban public transport connectivity.

Figure 7: Maps showing inter-urban connectivity, 2016

a) Car connectivity (peak time)



b) Congestion



c) Public transport connectivity (peak time)

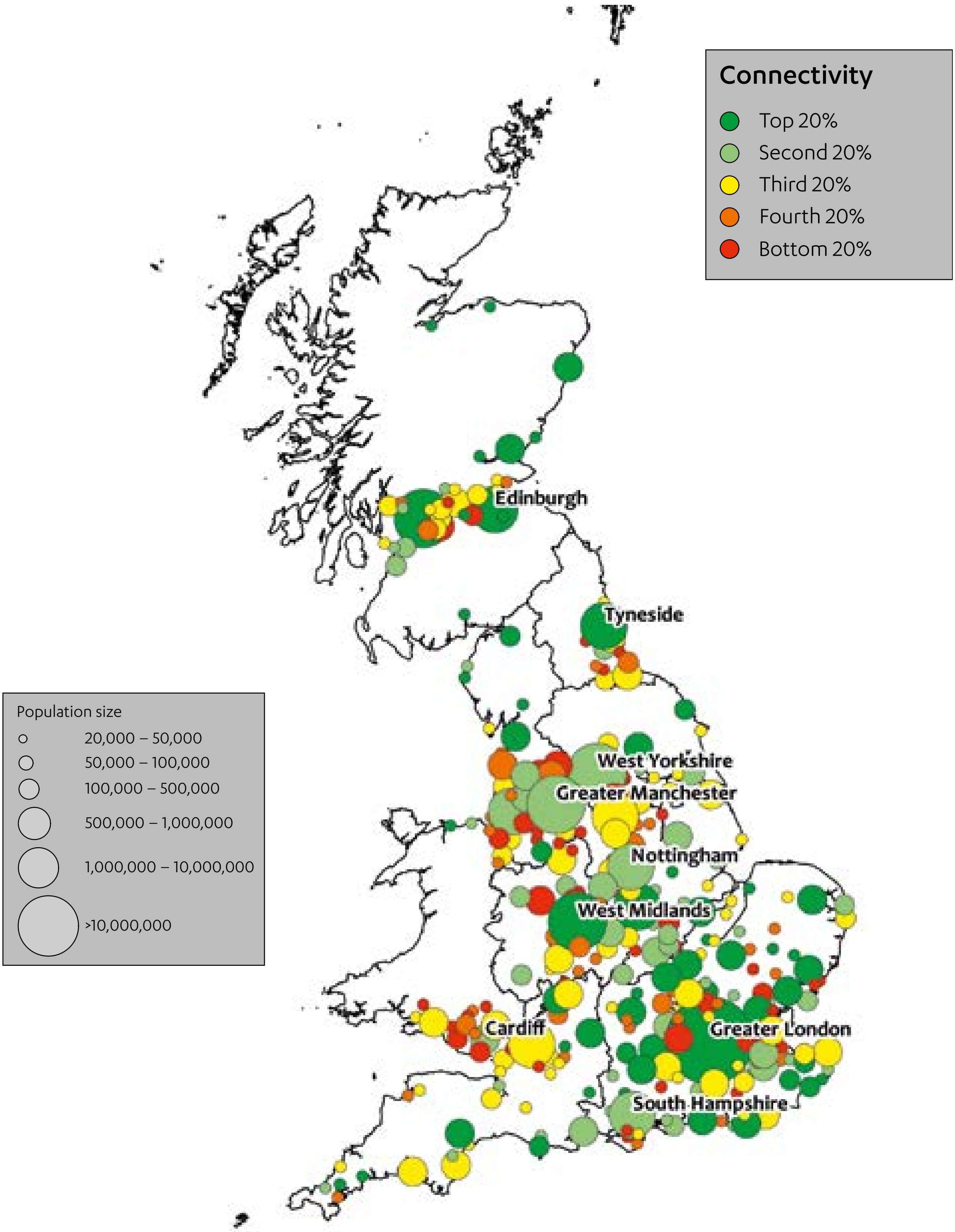


Table 8: Average inter-urban connectivity by region, 2016 (weighted by population in each built up area)[24]

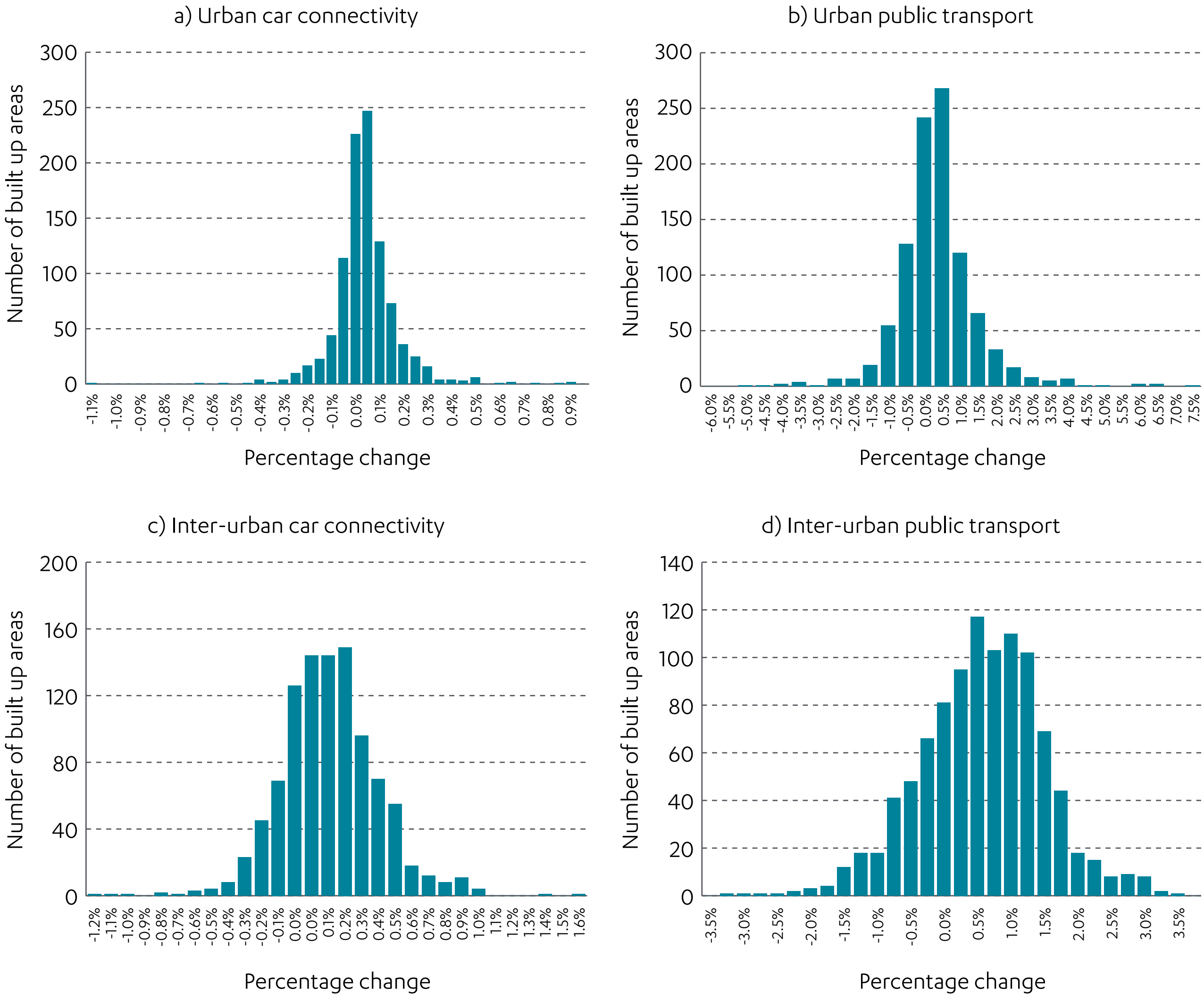
Region	Car	Public transport
West Midlands	1.28	0.07
Yorkshire and The Humber	1.19	0.05
East Midlands	1.05	0.06
East of England	1.02	0.06
South East	1.02	0.07
North East	0.95	0.06
South West	0.95	0.06
All built up areas	0.94	0.08
North West	0.92	0.06
Wales	0.89	0.05
Scotland	0.87	0.07
London	0.58	0.15

Changes in connectivity

Prospective measured connectivity according to the Commission's definition for 2011 and 2016, which enables analysis of the change in connectivity over this period.

Figure 8 shows the distribution of the change in connectivity between 2011 and 2016. As the charts suggest, there is little change over this time period across the vast majority of places. The change in public transport connectivity is shown to cover a much wider range both within and between places than the change in car connectivity. There have been modest, but widespread improvements in inter-urban connectivity, with most places improved whereas within urban areas the picture is much more mixed and on average there has been little improvement. This confirms, as highlighted in the National Infrastructure Assessment, that government has prioritised major upgrades to transport between cities. The Commission recommends that the next wave of major upgrades should increase the focus on transport within cities.

Figure 8: Percentage change in connectivity at peak within Great Britain's 1,000 most populated built up areas, between 2011 and 2016



A few interesting findings can be noted when looking at the ten highest and lowest built up areas ranked by percentage change. For urban connectivity, Liverpool, Sheffield and Coventry are the only large cities to be ranked in the top ten built up areas for public transport connectivity improvements. Liverpool has improved on both urban measures, with a 0.8% increase in car connectivity and a 4.0% increase in public transport connectivity (both ranking in the top ten). A likely reason for this improvement is the completion of major transport schemes across the city, such as the Edge Lane scheme in 2012 and the major junction improvements in 2016 which used funding secured from the Local Growth Fund.[25][26]

Plymouth is the only built up area with a population above 50,000 which is ranked within the top ten for the increase in inter-urban car connectivity, however this increase is only 1.0%. Birkenhead is similarly the only built up area with a population above 50,000 which ranked within the top ten for the change in inter-urban public transport connectivity, with an increase of 3.1%. This could also be due to the road improvements in neighbouring Liverpool, along with station improvements in Birkenhead itself.[27]

The majority of built up areas which are ranked in the ten lowest built up areas for the change in inter-urban connectivity are located in Scotland. This is interesting as Scotland was found to have both high and low outliers for the car and public transport connectivity values in 2016. There are a wide range of reasons which could be attributed to the change in connectivity observed. A likely cause are the physical constraints which might inhibit improvements in transport connectivity as demand increases.

Conclusions

As this paper has aimed to demonstrate, this data offers a range of information which spans across Great Britain.

Most places are well connected, at least relative to each other. Although there are no clear regional trends in the different connectivity values, patterns can be picked out which emphasise the role of population size in connectivity. Different patterns can also be observed which relate to proximity to other large cities, transport links such as motorways and rail stations, and physical constraints including peninsulas and bodies of water.

For urban connectivity, the largest challenges are in the big cities. Here the faster, straighter roads are not enough to deal with greater demands. Nor are things particularly getting better. Connectivity by both car and public transport tends to decrease with population size. More densely populated places are likely to have more traffic at peak time, which affects travel speeds into the centre and reduces connectivity. The congestion metric within places is also shown to deteriorate with population size. This could explain why public transport in larger cities has low connectivity, as many places are served by buses which are directly impacted by the congested roads.

For inter-urban connectivity, the faster, straighter roads between large places are generally sufficient to deal with the greater levels of congestion. And overall, connectivity is shown to be improving marginally. Inter-urban connectivity by car is shown to be substantially better than by public transport. The difference between transport modes is much greater than that of urban connectivity. Connectivity by car in some of the larger cities (West Midlands and West Yorkshire) is significantly better than average, whereas London is a clear outlier for car connectivity when compared to the other largest cities. By public transport, the bigger places are shown to be well connected, London especially. Roads provide better connectivity than public transport everywhere. Bigger places tend to be better served by rail which tends to reduce travel times relative to other modes (i.e. buses) and improves their connectivity.

Through looking at specific outliers in the data, further interesting findings can be developed. Notably places in Scotland are found to be high and low outliers for various connectivity values, highlighting the more extreme landscape and potentially their reliance on specific train routes.

Finally, although there has been little change in the connectivity values between 2011 and 2016, it is interesting to consider the places where there has been a more significant change. Looking into these specific places further starts to build a broader picture of the different constraints and opportunities which are impacting connectivity across Great Britain.

HOW TO PROVIDE INPUT

The Commission would welcome comments on this discussion paper. In particular, references to other sources of evidence on these issues would be helpful. In addition, the Commission would be interested in engaging on any analysis undertaken using this data. When using the data, please cite 'National Infrastructure Commission 2019 Transport Connectivity Data'. Please send any comments to **NICdiscussionpapers@nic.gov.uk**.

ANNEX 1: FORMULAS DEVELOPED BY PROSPECTIVE LABS TO CALCULATE THE CONNECTIVITY METRICS

For each city centre *i* Prospective calculate a set of urban and inter-urban connectivity indicators for each transport mode *m* and demand type *P* which represent the accessibility of each city centre to demand for *P*:

$$U_{im,p} = \sum_{j} W_{j,p} \times \exp\left(-ß_{p} \times t_{ijm}\right)$$

where, $w_{j,p}$ is the level of demand of type *P* in destination *j*, t_{ijm} is the travel time from city centre *i* to destination *j* using transport mode *m* and $ß_{p}$ represents that impact of distance/travel time on the attractiveness of city centre *i* to consumers in *j*. See Appendix 6 of Prospective's technical report for details on setting values for and the results of a sensitivity analysis.[28]

The above indicators are normalised by as-the-crow-flies equivalent metrics:

$$U'_{i,p} = \sum_{j} W_{j,p} \times \exp\left(-ß_{p} \times d_{ij}\right)$$

Where d_{ij} is the crow fly distance between *i* and *j*. The final normalised connectivity indicators $W_{im,p}$ represent the effectiveness of transport mode *m* in facilitating access to demand *P* from city centre *i* after the physical proximity (Euclidean distance) to the locations of demand has been accounted for.

$$W_{im,p} = {}^{U_{im,p}}\!/_{U'_{i,p}}$$

Where d_{ij} is the Euclidean distance between *i* and *j*. The normalisation process highlights the effectiveness of the transport infrastructure in serving the demand-supply system considering its distribution in space.

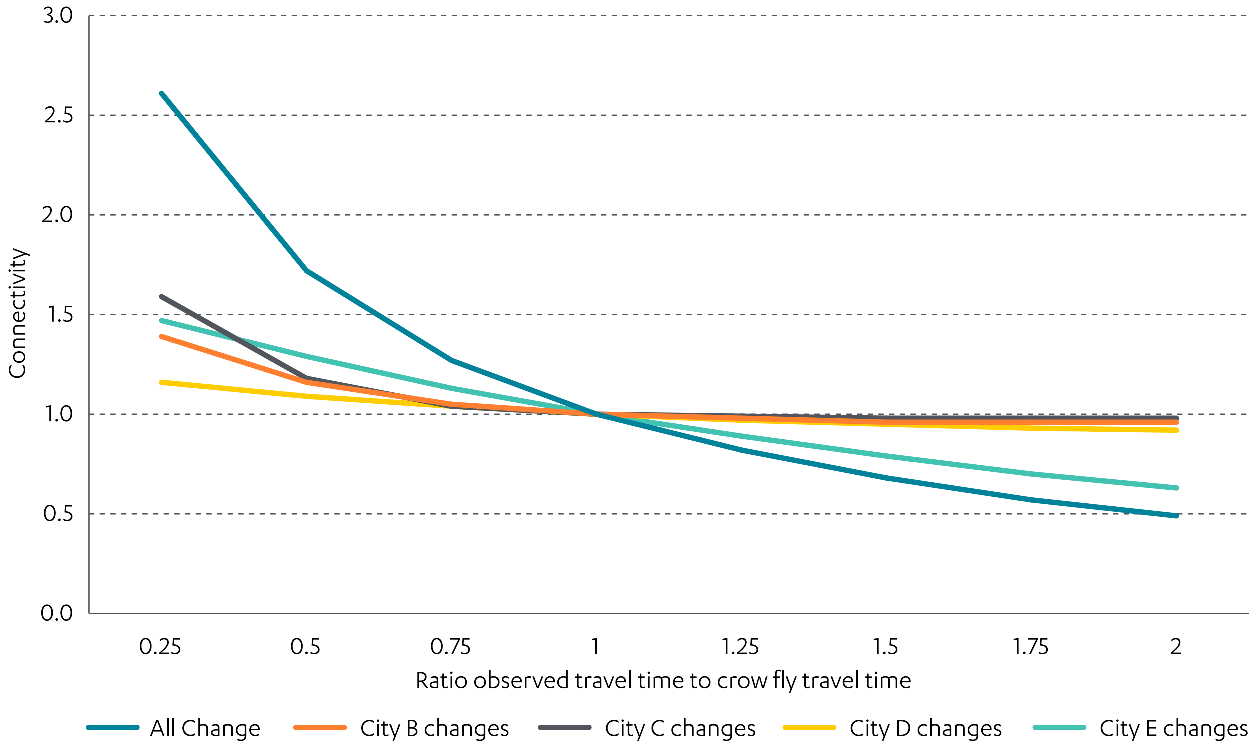
ANNEX 2: SIMPLIFIED EXAMPLES DEMONSTRATING THE IMPACT OF A CHANGE IN OBSERVED JOURNEY TIME ON CONNECTIVITY

Example scenario 1

	Distance from City A (km)	Population
City B	50	25,000
City C	75	50,000
City D	20	10,000
City E	10	40,000

The connectivity score, as measured, does not provide a linear relationship with average journey times. A change in connectivity score from, say, 0.5 to 1 does not necessarily mean you can travel twice as fast because it depends what has changed: this could be a result of population or travel time changes. The curves below show the change in connectivity which would occur in the above example if travel time to each place, or all places changed. Where the travel time changes in just one place, all other speeds are assumed to be constant at a ratio of one to the crow fly travel time.

Figure 9: The impact of a change in observed journey time on connectivity (scenario 1)



City D is shown to have the smallest impact on connectivity. This is due to the relatively small population in this city (10,000), which gives the city less weight in the connectivity calculation – even when the entire population is accessible it only makes up a small percentage of total connectivity. This is despite the fact that this is one of the closest cities to City A, at 20km. Intuitively this makes sense – for example, London is a more economically important connection to many cities than their nearer neighbours.

The largest range of impact on connectivity is caused by a change in the travel time to City E This can be explained by its close proximity to City A (10km) and large population (40,000).

For City B and C, the curves are relatively similar. City C is twice the size of City B, meaning that it has a marginally larger impact on connectivity despite being further away.

As the observed travel time increases the impact it has on connectivity flattens out. This is noticeable to the right of the chart for cities B, C and D. As the journey time to a place increases, its contribution to connectivity approaches 0 – but it can't be negative. Similarly, at speeds much higher than the 50km/h (crow fly) benchmark (lower journey times), the measure increases at an accelerating rate: as journey times fall, more distant places, which had little impact on connectivity when journey times were long, are weighted more heavily.

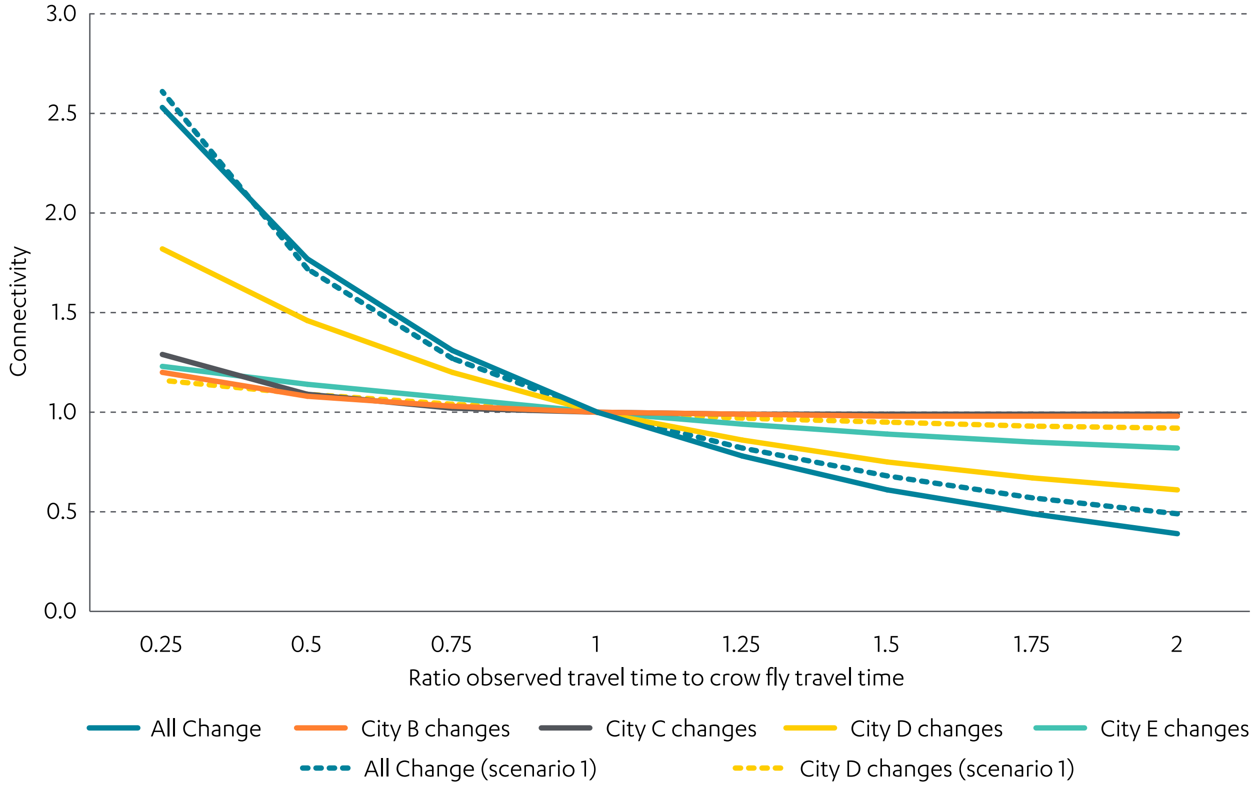
Example scenario 2

Changes in the population of any of the places would also impact on connectivity. Figure 2 is based on the same scenario as above, but the population of City D has increased from 10,000 to 100,000. The curves have been plotted following the same method.

	Distance from City A (km)	Population
City B	50	25,000
City C	75	50,000
City D	20	100,000
City E	10	40,000

In comparison to scenario 1, the curve for City D is shown to be significantly steeper and has a greater impact on connectivity. All other curves are now shown to be flatter, which indicates that they are now having a smaller impact on the overall connectivity value for City A. This demonstrates how larger places are given a greater weighting in the connectivity calculation, and can dwarf the impacts of connectivity connections to smaller places.

Figure 10: The impact of a change in observed journey time on connectivity (scenario 2)



Endnotes

1 National Infrastructure Assessment, July 2018. Available here: **https://www.nic.org.uk/assessment/national-infrastructure-assessment/**
2 Prospective: Transport connectivity report, July 2018. Available here: **https://www.nic.org.uk/supporting-documents/prospective-july-2018-transport-connectivity-report/**
3 Data. Available here: **https://nic.org.uk/publications/transport-connectivity-data/**
4 Department for Transport journey times to key services available here: **https://www.gov.uk/government/collections/journey-time-statistics**
5 Technical annex: Measuring infrastructure performance, December 2018. Available here: **https://www.nic.org.uk/publications/technical-annex-measuring-infrastructure-performance/**
6 Peak time was defined by Prospective as between 7am and 10am.
7 See the ONS census geographies overview for a description of the built-up area methodology. Available here: **https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography#built-up-area-built-up-area-sub-division**; for further details on Prospective's approach to defining built-up areas see Appendix 1 of the Prospective report.
8 For a list of cities included in the Centre for Cities definition see here: **http://www.centreforcities.org/city-by-city/**
9 Rural urban classification used for the 2011 census **https://www.gov.uk/government/collections/rural-urban-classification**
10 For the full list of built-up areas and corresponding cities see Appendix 5 of the Prospective report.
11 For details on how the value of this 'decay' parameter was set and sensitivity tests adjusting this value see Appendix 6 of the Prospective report.
12 For more information on the output area definition see the ONS census geographies overview. Available here: **https://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography#output-area-oa**
13 For further details see Appendix 2 of the Prospective report.
14 50km/h was chosen by Prospective based on their own assessment of the average speed which could be achieved across an unconstrained road network.
15 There are a small number of exceptions to this, as data was not available for every place in every year or at every time of day.
16 For a list of cities included in the Centre for Cities definition see here: **http://www.centreforcities.org/city-by-city/**
17 As an outlier, Lancaster University BUA has been excluded from figure 2. It was shown to have very high population density and good connectivity relative to other places. This is because it only covers a small area of land and has a large student population.
18 CGN0502b: Average delay on locally managed 'A' roads2: by local authority in England: annual from 2015 **https://www.gov.uk/government/statistical-data-sets/average-speed-delay-and-reliability-of-travel-times-cgn**. Note that the Department for Transport data is at the local authority level so cannot be directly matched to built up areas.
19 Maps only include built up areas with 20,000 or more inhabitants so as to allow for better visualisation of the data. This lower bound was selected as it includes all large towns (places with between 20,000-100,000 people), and represents close to 90% of the population.
20 Weighted average connectivity has been calculated for each region based on the population of each built up area within each region.
21 Berwick-upon-Tweed station information. Available here: **https://www.thetrainline.com/stations/berwick-upon-tweed**
22 Scottish rail routes and timetables. Available here: **https://www.scotrail.co.uk/plan-your-journey/timetables-and-routes**
23 Maps only include built up areas with 20,000 or more inhabitants so as to allow for better visualisation of the data. This lower bound was selected as it includes all large towns (places with between 20,000-100,000 people), and represents close to 90% of the population.
24 Weighted average connectivity has been calculated for each region based on the population of each built up area within each region.
25 Edge Lane scheme completion, BBC article 2012. Available here: **https://www.bbc.co.uk/news/uk-england-merseyside-18007657**
26 Local Growth Fund expenditure on major junction improvements, LEP 2016. Available here: **https://www.liverpoollep.org/news/delivery-of-first-growth-fund-transport-initiative/**
27 Birkenhead station improvements. Available here: **https://www.merseytravel.gov.uk/about-us/media-centre/news/Pages/Birkenhead-North-Station-improvements.aspx**
28 Prospective: Transport connectivity report, July 2018. Available here: **https://www.nic.org.uk/supporting-documents/prospective-july-2018-transport-connectivity-report/**

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