Stitching Together the Fabric of Space and Society

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An Investigation into the Linkage of the Local to Regional Continuum

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Abstract

To date, space syntax models have focused typically on relatively small areas up to the city scale. There have been very few models that take into account the entire network up to the regional scale, so the cumulative effects of micro-scale connections on regional networks is unknown, and the performance of the regional network as a function of the local area cannot be assessed. As such, a complete understanding of the ways in which regional centres are co-dependent and cities relate to their surrounding sub-centres is lacking.

This study models the entire road network at the regional scale, by dispensing with axial lines entirely and moving to a road-centre line model of the UK, the Ordnance Survey's Integrated Transport Network (ITN) layer. This layer includes the topological connections between roads, so that a complete topological model of the road network including the directionality of streets can be constructed quickly.

A region of the North of England - including Manchester, Bradford, Sheffield and Leeds - is analysed. Regional level angular analysis is shown to correlate well with overall movement in the network, while local level metric analysis is shown to correlate with the population density. It is hypothesised that combined measures that link the global to the local will uncover discontinuities in the continuum of space, and that these disruptions to the network will correspond to social deprivation. However, although such discontinuities exist, experimental linkage of the analysis to deprivation indices by census areas shows little conclusive evidence. In particular, it is clear that the complex web of spatial factors uncovered need investigation with more sensitive tools and smaller units of aggregation. The study highlights the need for a set of combined measures using microscopic spatial, economic, demographic, and land-use data, in order to further understand the relationship of spatial factors with social activity, while reinforcing standard space syntax results at the regional level.

1. Introduction

This paper puts into place a methodological framework for the analysis of regional areas. It shows that space syntax findings at the local scale are replicated at the regional scale, particularly relating space to movement and population density. However, the motivation for the paper is to start to address the complex of factors that surrounds the formation of social and economic outcomes at multiple scales. These require consideration of how patterns of potential mobility and social interaction may produce neighbourhoods and urban hubs, and how in turn, the cumulative effect of these relationships determine the social and economic synergy between hubs.

That there may be such co-dependencies - mediated through the fabric of spatial configuration - has started to attract attention from socio-economic theory. Cities are being understood not just as a single whole units, or even as sets of distinct areas, but as a complex, interlinked entities that affect and are affected by other centres within a region.

Lucci and Hildreth (2008) suggest that synergy between cities arises as a function of the spatial contingencies of the cities, the strength of infrastructure links between them, and the ability to develop complementary industries around an urban hub. They take the example of the combination of London and Reading, which appear to reinforce each other positively, while Manchester and Burnley do not, despite being physically separated by about the same distance, and having similar relative sizes. An important factor they identify is that Reading lies within London's travel-to-work area, whereas Burnley is relatively insular. They show data for the number of in- and out-commuters for both pairs centres, which points to the fact that people do not travel from Manchester to Burnley. Reading is much better tied into the infrastructure of London than Burnley is to Manchester, and this might seem the dominant factor in the relationship. However, there are more complex issues presented by looking at other pairings, such as Brighton and London; these also reinforce despite similar commute times to Burnley-Manchester. So one is forced to ask: what is it about the relationship that leads to the disparity? Is it primarily a spatial difference, or an economic one?

There is good evidence that increased wealth is correlated to increased mobility in general, so a case could be made that the bigger economy of London simply stimulates increased mobility, and thus a synergistic relationship at a further distance can develop through a virtuous circle of wealth creation. However, Echenique (2007) argues the opposite is the case, that growth is a product of mobility. His contention is that it is unlikely that the wealthy would travel more simply for the sake of it; if people travel, then it is because they fulfil a demand by doing so. He suggests that travel increases efficiency and therefore stimulates growth, and therefore, because infrastructure mediates the patterns of interconnections between centres, it either promotes or inhibits mobility; so the quality of infrastructure has a bearing on wealth. It is a compelling argument, but is it possible to prove? In order to do so, the quality of infrastructure linkage and the associated wealth of areas need to be analysed. However, it is important to acknowledge the complexity of the situation, that a generic 'mobility' is in fact the product of movement in different modes, for different purposes and at different scales.

The situation is made more complex by the nature of the centres under consideration. How is it that there comes to be a patchwork of poor and rich areas across regions rather than a uniform distribution of wealth? Webster (2003) argues that the city itself comprises an interlinked network of neighbourhoods, which are subject to both organisational order, as individuals pool resources within them, and institutional order whereby bodies seek to control scarce resources and reduce the costs of conflict over resources. These neighbourhoods are linked into the spatial framework (subject to a spatial order), so that infrastructure becomes one of the resources to manage, but at the same time, the infrastructure influences the size of neighbourhoods, their relationships and the social and economic contracts that bind adjacent neighbourhoods together. Any question about an area therefore needs to assess the strength of the spatial linkage around it and through it, as well as the physical placement of services within it.

In this paper, we will attempt to formulate methods to combine these ideas of mobility and neighbourhood, and stitch them into a spatial fabric in which social and economic activity take place. The paper is structured with a short background to recent innovations in the measurement of configuration, and the analysis zone to be investigated. The methodology section covers both the construction of measures in a system of topologically linked continuous road-centre lines and how these measures can be related to areal units as well as gate counts. With the framework in place, the paper will work through from movement, road-typology, place to social linkage, at each stage introducing concepts that will be used in the next section.

2. Background

The measures we shall apply are for the most part not novel. Instead, this study concentrates on how to combine existing measures of spatial configuration into a meaningful whole. The two major measures that will be used are segment-length weighted angular analysis (Turner 2007) and metric reach (Peponis et al. 2008). It will be shown that high radius angular analysis correlates with movement at the regional level, and that road typology also corresponds with this measure. It will also be shown that metric reach or low radius angular analysis are both reasonable correlates with population density, although the two measures are by no means independent. We can improve the correlation with population density if we use high radius angular analysis both to identify what is in effect the supergrid, and then remove those roads within it from the correlation. We can also create a combined measure for social analysis by linking the metric reach to the high radius angular analysis, so that the amount of angular analysis which is accessible can be measured. The unified measure means we can develop from a simple indicator of high population density, to an indicator of high population density that has good (or poor) linkage to the supergrid.

The space syntax literature has recently seen a number of other spatial measures introduced, where new angular methods mean that axial measures cannot be reproduced, but also in order to capture features of the configuration both more consistently and in more detail. In addition to metric reach, Dalton (2005) has defined a similar measure of accessibility, through the node count at various topological depths, which he calls 'vicinity'. We extend this measure to the case of a continuous road-centre line model using angle, and also use it to connect to the movement local grid and supergrid. Recent work has also concentrated on the identification of place (Dalton 2007; Hillier et al. 2007) and the close interrelation of many measures within space syntax. The reason for choosing the linkage of metric to grid is to break into the ground of spatially distinct measures. There is historical precedent in Read's (1999) definition of the supergrid, and the integration gradients that he proposes. Road-centre lines are not applicable to direct axial analysis, so Read's original definition of the supergrid cannot be reproduced. Further, with new angular measures it is possible to achieve a much finer resolution of derivation of the grid. We are also in a position to test ideas of supergrid, both from the perspective of road use and from the road typology proposed by planners.

3. Analysis zone

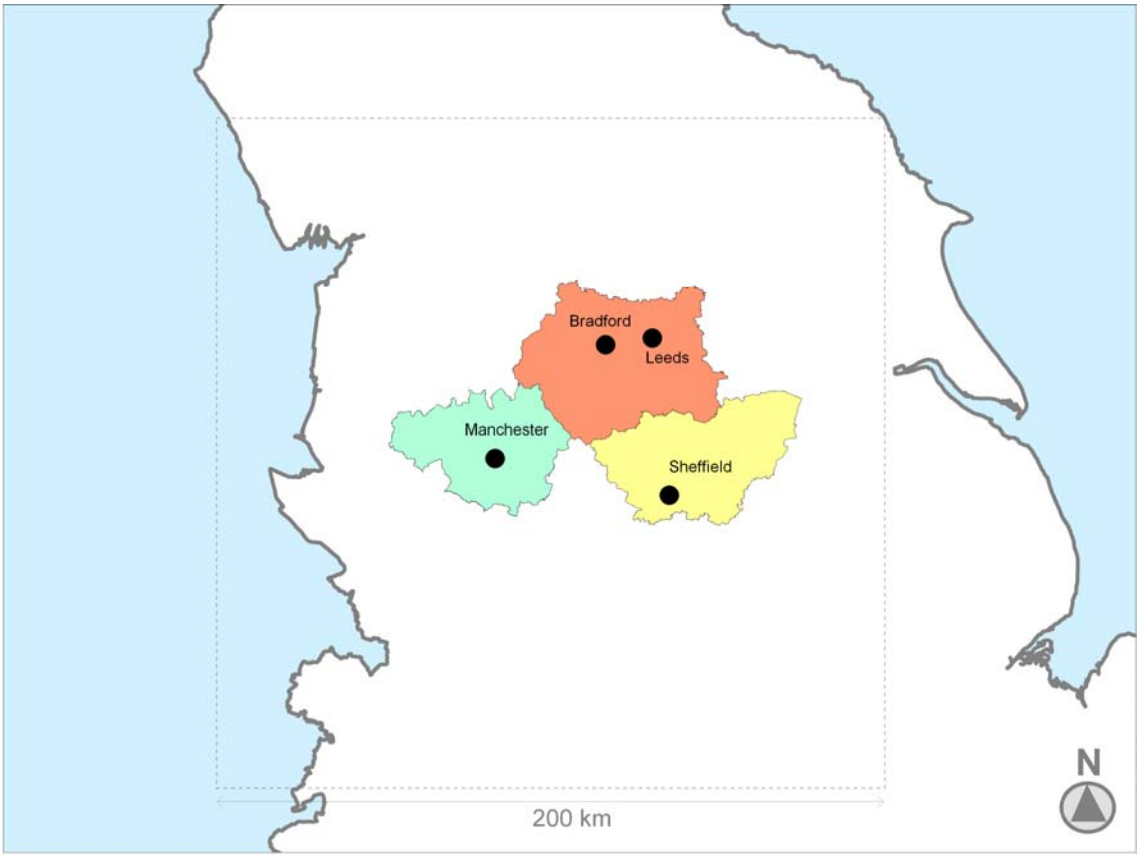

Figure 1

The analysis zone, encompassing the local authority areas of Greater Manchester (aqua), West Yorkshire (orange) and South Yorkshire (yellow), with the buffer used for analytic calculation, comprising Ordnance Survey tiles SD, SE, SJ and SK.

There is a history of inequality between the north and south of England (Townsend et al. 1998), and thus an interest in what factors may cause this divide. Until now, most analysis has used traditional economic theory, which is largely aspatial (although indices of deprivation include factors such as distance to shops). More recently however, there has been interested in how spatial factors may play a role, and in particular, Lucci and Hildreth (2008) have used census statistics - which include travel-to-work information - to construct in- and out- commuter numbers between various centres, and hence to start to build a spatial understanding of poverty. Lucci and Hildreth also focus on the north of England, and in particular the area around Manchester, but also including cities in Yorkshire such as Manchester and Bradford. To achieve some overlap between studies, for the purposes of this paper, an analysis zone based on local authority boundaries within England is taken, comprising Greater Manchester, West Yorkshire and South Yorkshire, with a total area of roughly 9700km^2 (see figure 1). The analysis zone covers several interlinked cities forming an approximate triangle. The large urban conglomeration of Manchester is to the west, the smaller cities of Bradford and Leeds to the north, and Sheffield to the south. All the cities were prominent in the industrial revolution, but have suffered as industry has declined. They have become the target of regeneration projects, with a large differential in success. In particular, both Manchester and Sheffield have seen increase in wealth at the town centres, which has largely eluded Bradford and Leeds, which are physically close (about 15km apart). Manchester is firmly tied into the infrastructure of the UK, with motorway links west to Liverpool, north to Preston and east to Bradford and Leeds (about 65km away by road). Both Leeds and Sheffield are on the major north south axis of the M1 motorway (separated by about 55km by road). However, Sheffield and Manchester are poorly linked due to the Peak District national park falling between them.

4. Road-centre lines for regional studies

Analysis within space syntax is increasingly turning to road-centre line analysis rather than the traditional axial analysis due to the wide availability of GIS data, and so that the lengthy process of construction of axial lines can be avoided, freeing up space syntax to macroscopic analysis of whole regions or countries (Dalton 2003; Jiang et al. 2007; Peponis et al. 2008; Turner 2007). In addition to the advantages of increased access to consistent data, there is also the advantage that methods have allowed authors to approach mechanistic reason for why space syntax correlations with movement and occupation may exist. In particular, it is thought that there may be a 'cognitive distance' in addition to a physical distance between places, and that new measures introduced based on angularity may approximate this distance (Hillier and Iida 2005).

The methodology has divided roughly into two. On one side, researchers have kept the notion of changes of direction as a primary factor of the analysis. This originates from the introduction of strokes (Thompson 2003) or continuity lines (Figueiredo and Amorim 2005), where the authors felt that small deviations in lines were accounting for unnaturally high accumulation of weight in the analysis. In response, they joined lines into single long continuity lines, allowing axial analysis to be carried out for large systems relatively efficiently. This process can easily be incorporated into geographic information systems (GIS), and so later authors have continued to adopt this strategy, including Jiang et al. (2007) and Peponis et al. (2008). From the perspective of cognitive distance, there is evidence that people do indeed make categorical distinctions between making a turn and making no turn, and that these have a bearing on the perception of distance travelled (Sadalla and Magel 1980; Jansen-Osmann and Wiedenbauer 2004). However, the implementation of this method requires that authors identify a 'continuation angle' whereby two lines are joined. Both Jiang et al. and Peponis et al. independently make the empirical choice of 10 degrees being the cut-off between a turn and no turn. This choice ultimately needs to be tied back to cognition, however, there is a second caveat to implementation. Necessarily continuity based approaches tend to only work at decision points, because while a junction is easy to identify, it is difficult to tell the difference between a slowly arcing line and a ninety degree bend. Once again, this may have a cognitive bearing, but it requires further analysis. As an alternative approach, the other group of researchers have tried to work with a summation of cognitive distance, by adding all the angles turned on a journey (Hillier and Iida 2005; Turner 2007). Both Hillier and Iida and Turner present some evidence that these measures approximate those of traditional integration analysis, and also make a case that their methods work in a cognitive sense. For the purposes of this paper we stick to angular measures, although both methods clearly have merits.

More importantly, from our perspective, Hillier and Iida and Turner both identify angular choice as the primary movement correlate in space syntax. This is perhaps a fairly straight-forward finding. Choice is the sum of all journeys that pass through a line segment, if those journeys take the shortest (angular or physical distance) path between all pairs of segments. Turner (2007) introduces the idea of segment-length weighting, so that shorter segments do not unnaturally weight the analysis, which we will follow here. In segment-length weighting, each journey is weighted by the length of the origin segment multiplied by the length of the destination segment, effectively creating all-to-all pairs of journeys from each point location along the two segments. For convenience, we shall call this measure simply *C*. *C* is typically calculated for journeys up to a certain physical distance, representing typically journey lengths. For the experiments here, *C* was calculated for radii between 500m and 40km.

Just as there is more than one approach for thinking about movement, there are also many methods that attempt to understand something about place, or the space of possible interactions. For the purposes of this paper, we shall turn to using mainly metric reach, which is simply the sum of accessible segment lengths within a certain physical distance. Naturally, this measure tends to correlate with density of road pattern, and thus, particularly locally, it can be used to identify urban centres. As a method, it is very similar to that introduced by Hillier et al. (2007), but with an appeal as a straight-forward measure. We implement this measure for local radii between 500m and 2000m, and call it simply *R*.

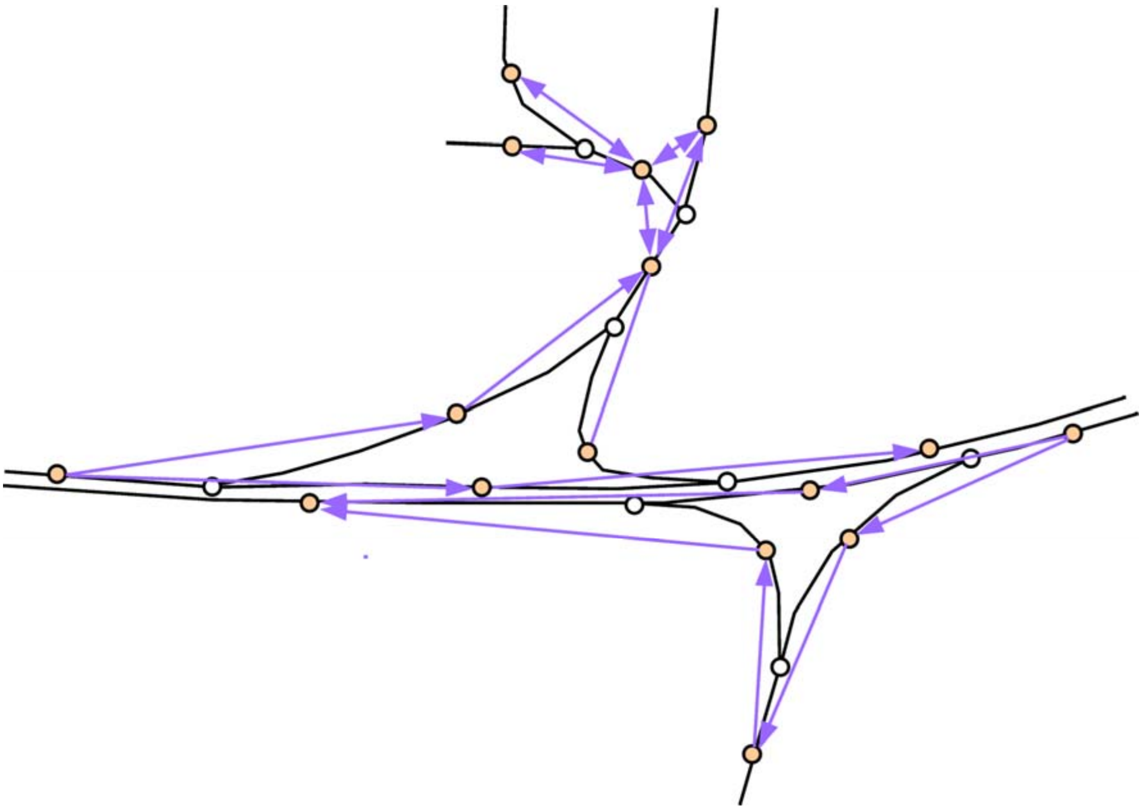

Figure 2
A dual carriageway intersection, with network topology superimposed. Segments are treated as midpoint to midpoint of inter-junctional stretches of road. Connections are directional and only exist when vehicles may turn move between the segments.

The measures were implemented as a plug-in for the Depthmap program (Turner 2007), so that they could work with macroscopic regional maps. The maps use the Ordnance Survey's Integrated Transport Network (ITN) layer, which is useful as it contains the topological connections between roads, including one-way streets, no right turn, and directionality on motorways. The plug-in reads the topological connections and thereby uses actually road access constraints for the calculation of the measures. This works well for urban and inter-urban systems, but of course it may have implications at the local level where we might prefer to look at pedestrian rather than vehicular movement.

Two approximations were made in order to deal with the very large system under consideration. The first is to join straight-line segments into inter-junction segments (following Jiang et al. 2007). This allows significant decrease in the complexity of the analysis, and it mitigates the effect of scaling in the representation. It is clear that we could then use an inter-junctional method to apply a strokes-like approach (Thompson 2003), but instead we apply a consistent rule in order to cope with segments with different levels of internal angle. All analyses are applied from midpoint to midpoint of lines, both for physical distance *and* angular measures. Note that the physical midpoint of a line may differ from its angular midpoint; in the angular version, the angular midpoint is used, so from one segment to the next, half of the angular turn within the first segment is added to the angular turn between the segments and half the angular turn within the second segment (figure 2).

The second approximation is the number of origin and destination pairs used for the analysis. Wilson (2000) observes that the road network forms an entropy effect, where major roads, by dint of their location, attract entropy. He suggests that the effect rapidly takes over any choice of origin and destination. We use this to the advantage of reducing processing time. In order to determine the possibility, C was calculated at radius 10km for 100% of origins (for routes to all available destinations), 10% of origins, 5% and just 1%, for the area including the analysis zone. The R^2 correlation coefficient is against percentage of origin and destination nodes is shown in table 1. The table shows that even if only 1% of segments are included as origins, the correlation between calculated values for every segment in the system is still 0.936. As the number of journeys generated increases by the square of origins and destinations, we would expect the effect to be greater still as the radius is expanded, and so for radii above 10km, 5% of nodes were used as origins as a safe approximation of the total system.

Percentage of origins used	R^2 with C radius 40km, 100% of origins used
100%	1.000
10%	0.994
5%	0.987
1%	0.936

Table 1
R2 correlation between C radius 40km for different numbers of origins

5. Movement

For movement analysis, data was taken from the GB National Road Traffic Survey 2007, which has traffic counts for A-roads and motorways. There are 1643 record traffic counts within the analysis zone. A slight difficulty arises as the data points are not particularly accurate, and contain counts for bi-directional movement. This is fine for two-way streets away from other objects, however, the values of C must be altered where dual carriageways and motorways occur, because the measure of C is *directional*. Hence, as a simple approximation, for all one-way segments we double the value of C and take the maximum value within 25m of the recorded data point [1]. It was quickly established that only C at relatively high radius (10km and above) correlates better with the movement data. Although unadjusted values of C correlate well with movement data, the distribution is skew and higher value points in both datasets pull the regression line straight. Therefore, a more accurate measure of R^2 is established by taking the square root of each variable. Table 2 presents the R^2 values for each radius analysis up to 40km (the maximum calculated). As can be seen, the correlation rises for each radius data, with a maximum fair correlation of 0.51. This figure is within the range of space syntax presented results to date. However, if examine the regression line, we can see that this figure may be improved by extending the radius (figure 3). A good model of regression should show the best-fit line going through the origin (Turner 2007), and the line is currently offset, with values underproducing.

C Radius	R^2 (raw data)	R^2 (fair)
10km	0.01	0.03
20km	0.17	0.21
30km	0.42	0.41
40km	0.59	0.51

Table 2

R^2 correlation between C and 1643 road traffic movement observations within the analysis area for different radius analysis

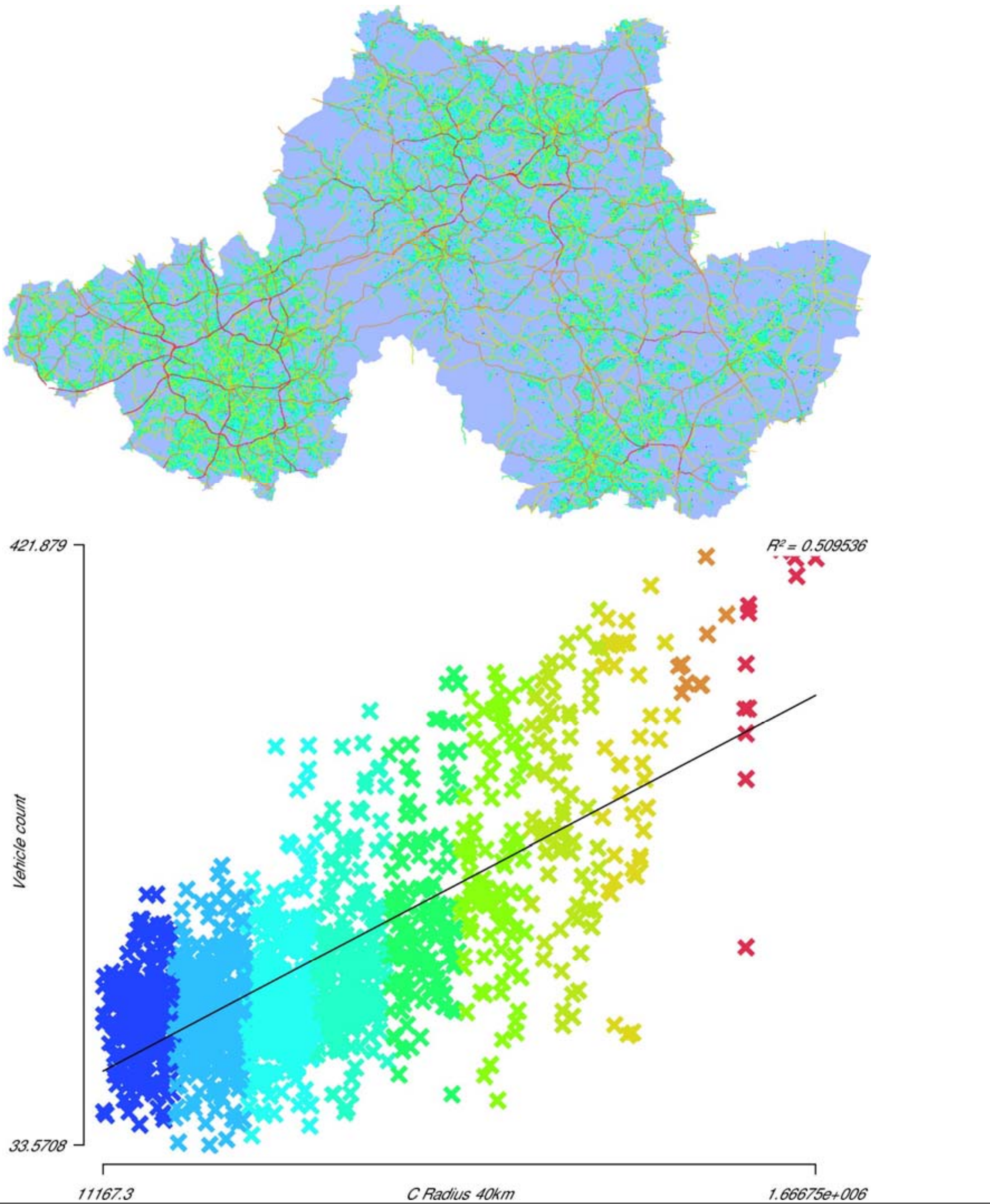

Figure 3

Top – C radius 40km analysis. Bottom – a scatter plot showing the correlation between movement and C radius 40km.

6. Road typology

Road Type	Count	Radius 10km	Radius 20km	Radius 30km	Radius 40km
Motorway	2606	0.18 (0.13)	0.26 (0.14)	0.39 (0.19)	0.46 (0.21)
A-Road	32684	0.31 (0.17)	0.25 (0.15)	0.26 (0.17)	0.24 (0.16)
B-Road	12250	0.25 (0.14)	0.19 (0.12)	0.18 (0.13)	0.16 (0.12)
Minor Road	43409	0.16 (0.11)	0.11 (0.08)	0.11 (0.09)	0.10 (0.08)
Unclassified	271254	0.04 (0.03)	0.02 (0.03)	0.02 (0.03)	0.02 (0.03)

Table 3
Average values of C for different radii (standard deviation in brackets) for different types of roads within the analysis zone

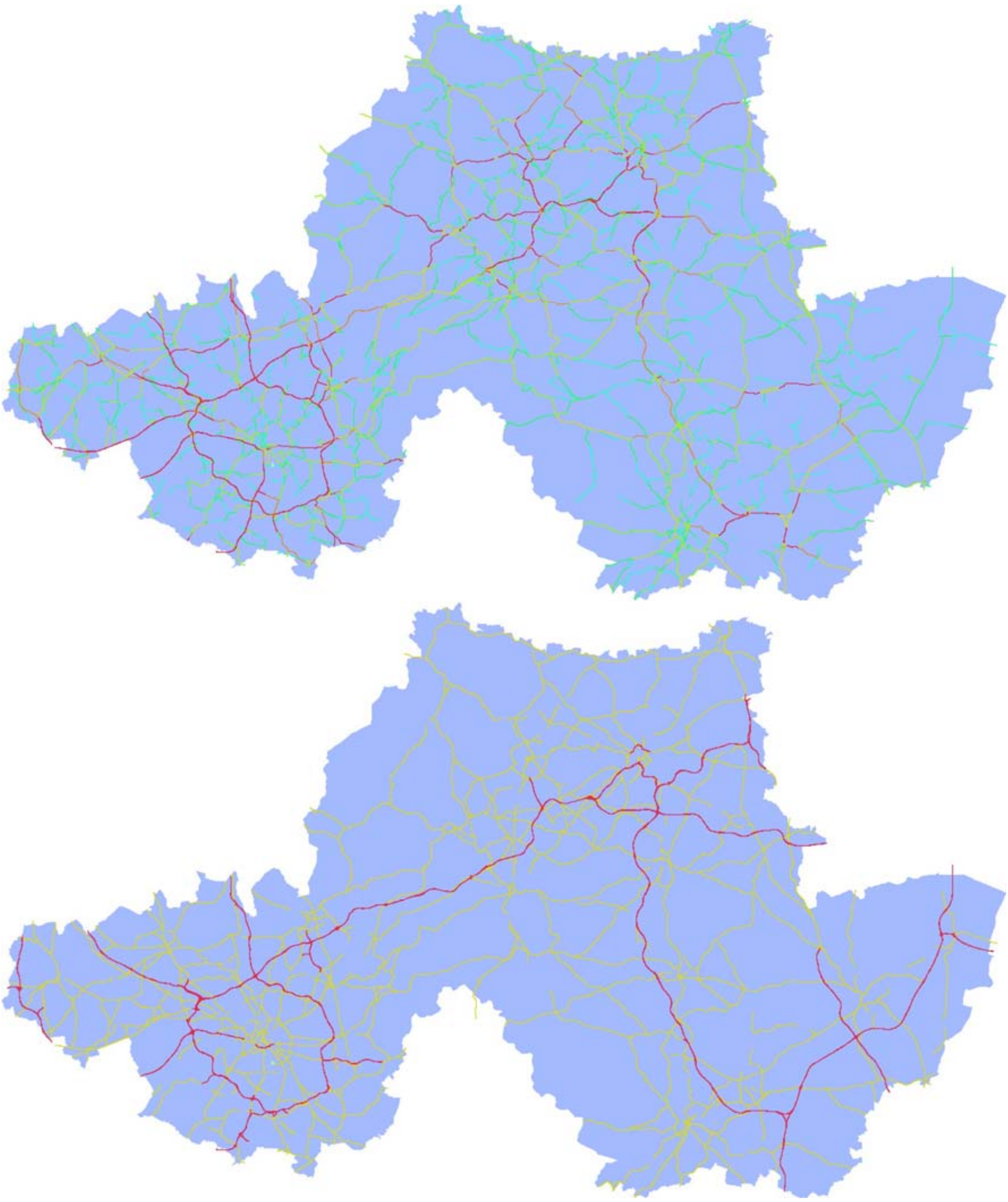

Figure 4
Top – Supergrid as identified by C radius 40km analysis. Bottom – Motorways (red) and A-Roads (orange) as they actually are.

Just as it is possible to construct a correlation between movement and choice, it is possible to examine if there is a relationship between road typology (as designated by the Highways Agency) and choice. As a measure to construct against social or economic variables, this has no value, as the typology is purely a construction of the planner. However, it does lead us to realise that it may be possible to identify a supergrid. Table 3 shows average and standard deviation of choice for each band of roads designated for various radii. Note that as we might expect, the high radius is the most distinguishing. At lower radii, journeys may be between local origins and destinations and thus show higher values on roads that planners may not associate with the overall hierarchy of the infrastructure network. However, they may well play an important part. For example, at walkable choice measures, they may correlate to town centres.

As choice radius 40km is the most distinguishing, we can pull out an ***anticipated*** network of A-roads and motorway by choosing roads above the A- to B- road means from table 3. This is not exact, as it is clear that the roads overlap to some extent. Indeed, roads that have higher flows may not be designated as motorways or A-roads, so this only to be expected. Figure 4 shows the result of performing this calculation, with the supergrid as identified by choice, and as by designated by the Highways Agency. As suggested, this is not necessarily useful as described. However, the supergrid has another property: it defines roads that are unlikely to have dwellings along them. Thus, if we are to move to a comparison of analytic measures with census statistics as we will in the following sections, then we may want to exclude the supergrid from any aggregate statistics collected about analytic values within an areal ward or output area for which we have socio-economic data.

7. Place and population density

So far we have applied analysis in a fairly standard manner for space syntax studies. However, if we are to move to understand socio-economic variables then we will have to examine the available data. Data from the UK's 2001 census is easily accessible and includes measures of socio-economic well-being and general population statistics. At its most detailed, it is made available for aggregated units called 'output areas'. These typically comprise around 100 dwellings, although some have many more. The borders are adjusted to numbers of dwellings, so in rural areas they are relatively large and in urban areas they are relatively small. This in itself poses problems for analysis based on using them.

For the purposes of this study, we will start by trying to examine the notion of a place. Many different variations have been suggested on this format. Two recent studies include Dalton (2007) and Hillier et al. (2007). One thing that is picked up by these studies is the scale of the grid increases. This is of course fairly self-explanatory. At a town centre the grid intensifies and generally population might be expected to increase (other than in shopping areas - more of which in a moment).

As a basic start, we can look at measures that may prove useful. These should be local measures, which can capture grid intensity, and metric reach is an obvious candidate. Figure 5 shows the metric reach at radius 1000m, which seems to draw out the areas of urban density. We investigate the census variable of population density, based on the population in each output area divided by its area for 19047 output areas within the analysis zone [2]. For each output area we take the average value of the segments passing through it to compare with the dependent variable. Table 4 shows the correlation with population density at different radii. However, as we noted in the last section, there may be elements of the supergrid passing through output areas and skewing this result. Therefore, in addition, we take out the supergrid from average values passed to the output area layer. This improves the correlation somewhat. It is also worth noting that other local measures, such as *C* radius 500m show a tendency to correlate with population density. This could well be because they are also affected by grid intensification (the number of journeys scaling with the square of the numbers of origins and destinations means that simply more journeys take place in grid intensified zones).

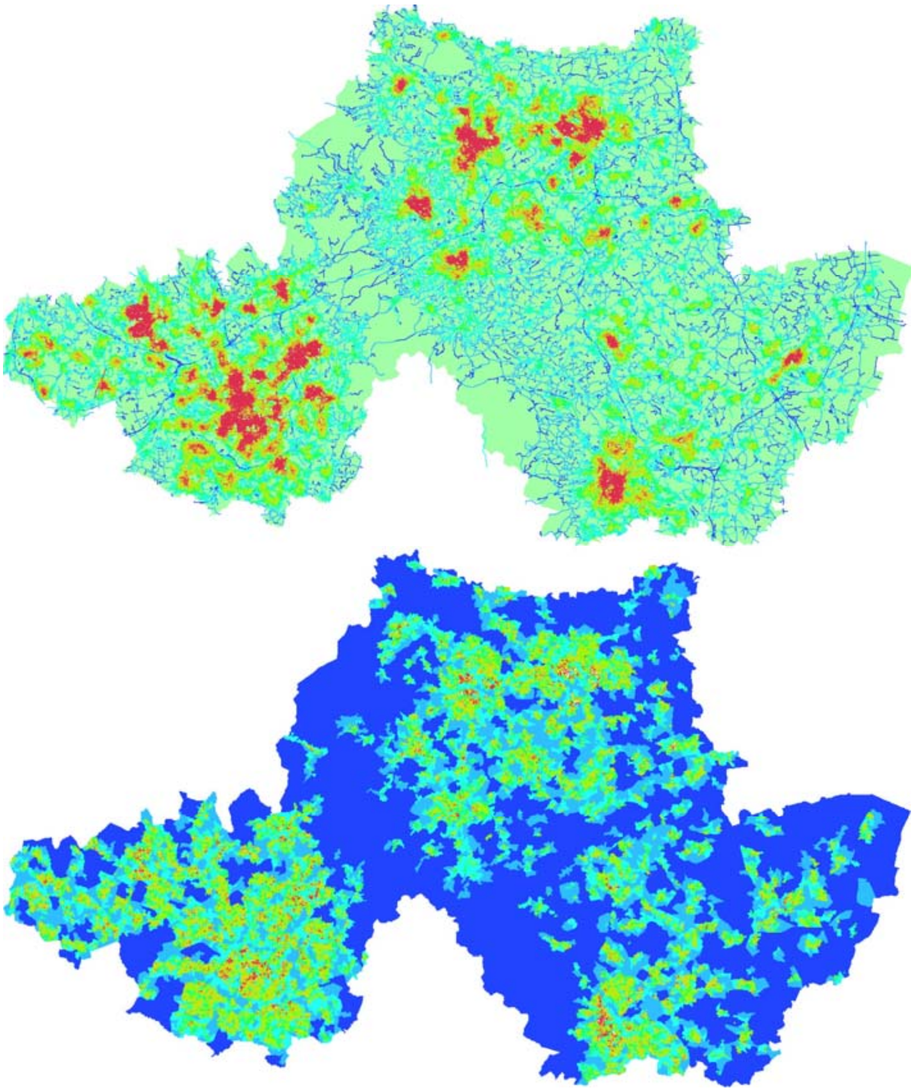

Figure 5

Top – Local grid intensification picked out by R radius 1000m. Bottom – Population density by output area for the analysis zone (source: 2001 census, Crown copyright).

Measure	Correlation (with supergrid)	Correlation (without supergrid)
R radius 500m	0.18	0.20
R radius 1000m	0.21	0.23
R radius 1500m	0.20	0.21
C radius 500m	0.20	0.22
C radius 1000m	0.18	0.20
C radius 1500m	0.12	0.14

Table 4

Correlation of measures of local accessibility and movement with population density

8. The spatial fabric and application to social statistics

The measures discussed so far have been confined to standard analysis. We also investigated measures against levels of poverty from the census statistics. Only very poor correlations were found. We repeated previous findings that the wealthy tend to avoid local choice - at R500m there is a negative correlation with the proportion of AB social class of $R^2 = 0.11$, while the poor, perhaps by reason of having no option, live in areas with somewhat higher local choice. There is a positive correlation with poverty (proportion of DE social class) with $R^2 = 0.11$. At this point, one might note that this, surely, is a similar finding to that in the previous section: surely it is telling us that the wealthy live in low density housing, and the poor in high density housing? For this, we attempt the same correlation with metric reach 1000m. It does show a similar effect, but not quite to the same extent: this time a 0.09 correlation with rich and 0.07 correlation with poor. This would suggest that there is something about the configuration, over and about the density which leads to the rich avoid the location - perhaps the avoidance of actual movement, while remaining in dense locations. However, there is a final twist: the population density does not show the effect to nearly the same extent, with $R^2 = 0.5$ (rich) and $R^2 = 0.03$ (poor). Perhaps, after all, there is spatial configuration at play.

In this vein, it was decided to attempt a couple of further hypotheses. Firstly, that the poor live close to the supergrid, and the rich may live away from it. This was tested by weighting the metric reach variable. Rather than summing the reach, it was summed according to the radius 40km choice value. Unfortunately, no significant correlation was found ($R^2 < 0.01$). Secondly, that the rich might have better access to shopping districts, indicated by high radius 2000m choice values was also found not to be the case.

9. Conclusion

We have attempted to create an integrated framework for the analysis of regional areas, using combined measures of accessibility and movement. While we can at least find good correlation with movement, and create a measure for the typology of roads based on high radius choice measures of space (at radius 40km, that is, approximating journeys of 40km), it has proved difficult to find good correlation with aggregate census statistics, including population density and deprivation. The case of population density demonstrates the difficulty of work with aggregation units, with often varied spatial types within single census output areas. We proposed to mitigate at least some of the effect by looking at the measures outside the supergrid in streets where people actually live. This certainly improved correlation, but only to a minor extent. This, of course, is for a measure which has a facile relationship with urban density. This problem is exacerbated when we move to social predictions. These can give only very vague indications of propensity towards wealth or poverty. It appears that more detail is required, with more disaggregated data, where it is possible to use the same detailed analysis that is conducted for movement data.

Notes

1 This method assumes that, where a street is near an intersection, we are interested in the road with the higher movement and higher value of C. Given that the data are recorded for A-roads and motorways only, this is a reasonably safe assumption. It also assumes that all one-way street segment is a carriageway of a dual carriageway or motorway. This may falter in built up areas where A-roads may actually be one-way streets.

2 Some output areas have unusually high population density, orders of magnitude higher than usual. On further examination, it was discovered that these occur in a very few cases where the area of the output area is so small that slight variations will skew the population density greatly. Thus we excluded 491 output areas from a total of 19538 areas (2.5%) within the analysis zone leaving the 19047 quoted in the text.

Acknowledgments

Data sources: Census data 2001 Census data from Standard Area Statistics (England and Wales), Crown copyright 2001, used with kind permission. Output area and administrative areas from UK Borders EDINA service, Crown copyright 2001, used with kind permission. Road centre lines from Ordnance Survey ITN Layer data, Crown copyright 2005, used with kind permission. Road usage data from the 2007 GB National Road Traffic Survey, DfT, Crown copyright 2007, used with kind permission.

References

Dalton, Nick Sheep. 2005. New Measures for Local Fractional Angular Integration or Towards General Relitivisation in Space Syntax. Paper presented at the *5th International Space Syntax Symposium,* TU Delft, Delft.

Dalton, Nick Sheep. 2007. Is neighbourhood measurable? Paper presented at the *6th International Space Syntax Symposium*. ITU, Istanbul.

Dalton, Nick Sheep, John Peponis and Ruth Conroy Dalton. 2003. To tame a TIGER one has to know its nature. Paper presented at the *4th International Space Syntax Symposium*. London, UK.

Echenique, Marcial. 2007. Mobility and income. *Environment and Planning A* 39:1783-1789.

Figueiredo, Lucas and Luiz Amorim. 2005. Continuity lines in the axial system. Paper presented at the *5th International Space Syntax Symposium*, TU Delft, Delft.

Hillier, Bill and Shinichi Iida. 2005. Network and psychological effects in urban movement. *Spatial Information Theory, Lecture Notes in Computer Science* 3693:475-490.

Hillier, Bill and Alasdair Turner and Tao Yang and Hoon-Tae Park. 2007. Metric and topo-geometric properties of urban street networks. Paper presented at the *6th International Symposium on Space Syntax*, ITU, Istanbul.

Jansen-Osmann, Petra and Gunnar Wiedenbauer. 2004. The influence of turns on distance cognition: new experimental approaches to clarify the route-angularity effect. *Environment and Behavior* 36:790-813.

Jiang, Bin, Sijian Zhao and Junjun Yin. 2007. Self-organized natural roads for predicting traffic flow: a sensitivity study. *Journal of Statistical Mechanics: Theory and Experiment* July, P07008.

Lucci, Paula and Paul Hildreth. 2008. Integration and Isolation. In *City Links,* The Northern Way, Newcastle.

Peponis John, Sonit Bafna and Zongyu Zhang. 2008. The connectivity of streets: reach and directional distance. *Environment and Planning B: Planning and Design* 35:881-901.

Read, Stephen. 1999. Space syntax and the Dutch city. *Environment and Planning B: Planning and Design* 26:251-264

Sadalla, Edward K., Stephen G. Magel. 1980. The Perception of Traversed Distance. *Environment and Behavior* 12:183-193.

Thompson, Robert C. 2003. Bending the axial line: smoothly continuous road-centre line segments as a basis for road network analysis. Paper presented at the *4th International Symposium on Space Syntax*, Atlanta, Georgia.

Townsend, Peter, Peter Phillimore and Alastair Beattie. 1998. *Health and Deprivation: Inequality and the North*. Abingdon: Routledge.

Turner, Alasdair. 2007. Depthmap. Computer program. London: University College London.

Turner, Alasdair. 2007. From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B: Planning and Design* 34:539–555.

Webster, Chris. 2003. The nature of the neighbourhood. *Urban Studies* 40:2591-2612.

Wilson, Alan G. 2000. *Complex Spatial Systems.* Harlow: Prentice Hall.